

22/PR-15

10/523273

DT05 Rec'd PCT/PTO 31 JAN 2005

1

**METHOD OF TREATING INFLAMMATORY ARTHROPATHIES
WITH SUPPRESSORS OF CpG OLIGONUCLEOTIDES**

CROSS REFERENCE TO RELATED APPLICATIONS

5 This claims the benefit of U.S. Provisional Patent Application No. 60/400,826, filed August 1, 2002, and to U.S. Provisional Patent Application No. 60/401,631, filed August 6, 2002, both of which are incorporated herein by reference in their entirety.

FIELD OF THE DISCLOSURE

10 The present disclosure relates to oligodeoxynucleotides that suppress an immune response to CpG oligodeoxynucleotides, and to the use of these suppressors in preventing or treating inflammatory arthropathies.

BACKGROUND

15 Arthritis, an inflammatory disease that affects the synovial membranes of one or more joints in the body, is the most common type of joint disease. Billions of dollars are spent annually for the treatment of arthritis and for lost days of work associated with the disease. The disease is usually oligoarticular (affects few joints),
20 but may be generalized. The joints commonly involved include the hips, knees, lower lumbar and cervical vertebrae, proximal and distal interphangeal joints of the fingers, first carpometacarpal joints, and first tarsometatarsal joints of the feet.

One type of arthritis is reactive arthritis, which is an acute nonpurulent arthritis secondary to a urinary tract or gastrointestinal infection with a variety of
25 microorganisms, including *Chlamydia trachomatis*, *Yersinia*, *Salmonella*, *Shigella*, and *Campylobacter*. Microbial components (and not live organisms) are found in the affected joints. The arthritis appears abruptly and tends to involve the knees and ankles, but sometimes involves the wrists, fingers, and/or toes. Untreated, the arthritis lasts for about a year, then generally abates and only rarely is accompanied
30 by ankylosing spondylitis. Despite evidence of disease being triggered by bacterial

infection, viable bacteria are rarely present in affected joints and antibiotic treatment seldom provides relief.

Up to 16% of subjects with gastrointestinal (GI) infection by *Salmonella* or *Shigella* subsequently develop arthritis. Despite this temporal association, it is unclear whether live bacteria reaching the affected joint are the cause of this arthritis. To date, success in culturing viable microorganisms from the affected joints has been quite limited, and antibiotic treatment rarely is of benefit. Symptomatic treatment is often accomplished with high doses of non-steroidal anti-inflammatory agents. In addition, intra-articular steroid injections are of use. However, a need remains for additional therapies for this disease.

Rheumatoid Arthritis (RA) is a chronic, systemic, inflammatory disease that affects the synovial membranes of multiple joints. RA considered an acquired autoimmune disease, and genetic factors appear to play a role in its development. In most cases of RA, the subject has remissions and exacerbations of the symptoms. Rarely does the disease resolve completely, although at times the symptoms might temporarily remit.

Symptomatic medications, such as non-steroidal anti-inflammatory agents and aspirin, analgesics, and glucocorticoids, are used in the treatment of rheumatoid arthritis to help reduce joint pain, stiffness and swelling. In addition, low doses of methotrexate, leflunomide, D-Penicillamine, sulfasalazine, gold therapy, minocycline, azathioprine, hydroxychloroquine (and other anti-malarials), and cyclosporine are used to modify the progression of the disease. However, a need still remains for other agents that can be used to alter the progression, or ameliorate the symptoms, of this disease.

In view of the above, there exists a need for new therapies to treat inflammatory arthropathies, particularly agents that suppress the inflammation associated with arthritis

BRIEF SUMMARY OF SPECIFIC EMBODIMENTS

Disclosed herein are oligodeoxynucleotides that can be used to suppress immune activation. These suppressive oligodeoxynucleotides are of use in

preventing and/or treating inflammatory arthropathies, such as, but not limited to, reactive arthritis and rheumatoid arthritis. The suppressive oligodeoxynucleotides can be administered locally or systemically. One specific, non-limiting example of local administration is by intra-articular injection.

5 A substantially pure or isolated oligodeoxynucleotide (ODN) is disclosed herein that is at least about 8 nucleotides in length, forms a G tetrad, has a CD value of greater than 2.9, has at least two guanosines, and suppresses an immune response. Optionally, the suppressive ODN has multiple guanosine-rich sequences, and in some examples, the ODN has one or more TTAGGG motifs. Furthermore, in
10 particular embodiments, the ODN is modified to prevent degradation or is part of an oligodeoxynucleotide delivery complex that includes a targeting moiety. In one specific, non-limiting example the suppressive ODN suppresses CpG-DNA-induced immune activation. Also disclosed herein is a pharmacological composition that includes the suppressive ODN and a pharmacologically acceptable carrier.

15 A method is disclosed herein for treating or preventing an inflammatory arthropathy in a subject. The method includes administering a therapeutically effective amount of the suppressive ODN to a subject having or at risk of developing an inflammatory arthropathy, thereby treating or preventing the inflammatory arthropathy.

20 In another embodiment, a method of treating or preventing an inflammatory arthropathy in a subject that includes contacting immune cells with the suppressive ODN *in vitro*. The immune cells are and transferred to a subject having or at risk of developing an inflammatory arthropathy.

Also described herein is a kit for treating or preventing inflammatory
25 arthropathies in a subject that includes the suppressive ODN and instructions for administering the ODN to a subject.

BRIEF DESCRIPTION OF THE FIGURES

Fig. 1 is a set of diagrams of the structure of a G-tetrad. Fig. 1A is a diagram
30 of the structure of an individual G-tetrad that shows the Hoogsteen base pairing. M^+ represents a monovalent cation such as K^+ or Na^+ and dR is the sugar-phosphate backbone. Fig. 1B is a schematic representation showing the possible folded

intramolecular quadruplex structure. Fig. 1C is a schematic showing the GG-base pair formed by means of Hoogsteen hydrogen bonds. Fig. 1D is a schematic of an intramolecular hairpin.

5 Fig. 2 is a set of graphs showing the effect of CpG ODN and suppressive ODN injection into the knee. Fig. 2A is a graph of joint swelling in mice treated with CpG ODN (solid circle), CpG plus control ODN (solid square), CpG plus suppressive ODN (open diamond), control ODN (open triangle), suppressive ODN (inverted open triangle), or PBS (open square, N = 8-11 mice/group). Fig. 2B is a
10 graph showing histologic changes in the injected knees. Knees were evaluated four days after treatment by a blinded investigator. Scale: 0; no inflammation, 1; sparse, localized perivascular infiltrate, 2; moderate infiltrate, 3; moderate - dense infiltrate with synovial hyperplasia. Fig. 2C is a graph showing that suppressive ODNs suppress joint swelling. At T=0, both knees were injected with 25 µg of CpG ODN.
15 The right knee was then injected with PBS and the left knee with 25 µg of suppressive ODN either 0 (solid circles, N=3), 24 (solid squares, N=6) or 48 (solid triangles, N=6) hours later. Results show the difference in swelling between the two knees. Statistical significance was assessed by repeated-measures ANOVA using the Proc Mixed procedure (Fig. 2A, 2C) and Wilcoxon Rank sum test (B). The
20 asterisk (*) indicates that $p < 0.05$.

Fig. 3 is a set of digital images of a photomicrograph showing the effects of CpG and ODN injection on knee histology in mice. BALB/c knees were injected with PBS (Fig. 3A, B), CpG ODN (Fig. 3C, D), CpG plus control ODN (Fig. 3E, F)
25 or CpG plus suppressive ODN (25 µg of each ODN, Fig. 3G, H). Typical histology four days after injection of 25 µg of each ODN is shown. Note the cellular infiltrates, perivascular accumulation of mononuclear cells, and hyperplasia of the synovial lining in the knees of mice injected with CpG ODN. Figs. 3A, 3C, 3E and 3G show 100x magnification; Figs. 3B, 3D, 3F, and 3H show 400x magnification.

30

Fig. 4 is a set of graphs that demonstrate that administration of suppressive ODN decreases TNF α upregulation following CpG ODN injection. Fig. 4A is a

graph of TNF α levels following treatment with ODN. BALB/c spleen cells were stimulated *in vitro* for 72 hours with 1 μ M of various ODN. Fig. 4B is a graph of percent tumor necrosis factor alpha (TNF α) production versus suppressive ODN concentration. RAW 264.7 cells (106/well) were stimulated with 1 μ M CpG plus increasing amounts of suppressive ODN. The concentration of TNF in culture supernatants after 24 hours was measured by ELISA. Data represent the mean + SEM of 5 independently studied animals/group. Statistical significance was assessed by Wilcoxon Rank sum test. Fig. 4C is a digital image of an agarose gel. Joints injected with 25 μ g of ODN were processed into RNA 3 days later. Representative examples of local TNF and β -actin mRNA levels are shown. Fig. 4D is a graph of relative TNF α mRNA expression following treatment with CpG ODN or CpG ODN and suppressive ODN. Relative intensity of TNF α vs β -actin mRNA (N=3). The asterisk indicates that $p < 0.05$.

Fig. 5 is a graph showing that the local administration of suppressive ODNs reduces the pro-inflammatory effect of CpG ODN administration. Optimal suppression of CpG ODN-mediated joint inflammation is attained when the suppressive ODN are administered three days before the inflammatory challenge. Shown is the mean and standard error of measurement (SEM) of 10-11 mice/group pre-treated locally (intra-articularly) with suppressive ODN three days prior to CpG ODN challenge (open circles), suppressive ODN administered one day prior to CpG ODN challenge (open, inverted triangles), suppressive ODN administered at the time of the CpG ODN challenge (open triangles). The joint swelling of mouse knees injected with control ODN (black diamonds) or phosphate buffered saline (PBS; black circles) three days before the CpG serve as controls.

Fig. 6 is a graph showing that naive mice (and mice pre-treated with control ODN or PBS) developed severe arthritis following local CpG ODN challenge. In contrast, systemic administration of suppressive ODN three days prior to local CpG DNA challenge reduced joint swelling and inflammation by 80 - 85% ($p < 0.029$). BALB/c mice were treated IP with 300 μ g of suppressive ODN 0-3 days prior to the intra-articular injection of 25 μ g CpG DNA. Consistent with previous studies, naive

mice (and mice pre-treated with control ODN or PBS) developed severe arthritis following local CpG ODN challenge.

Fig. 7 is a pair of graphs showing that systemic administration of suppressive ODN three days prior to local CpG DNA challenge reduced joint swelling and inflammation by 80-85% ($p < 0.029$).

Figs. 8A and 8B are a pair of graphs showing that systemically administered suppressive ODN elicit a population of regulatory cells that inhibit CpG-induced arthritis. As expected, spleen cells from untreated donors had no effect on the development of CpG-induced arthritis. By comparison, the transfer of 20×10^6 spleen cells from suppressive ODN treated donors significantly reduced joint swelling and inflammation in the recipients.

Fig. 9 is a graph showing that $CD11c^+$ cells are responsible for the resistance to CpG-induced arthritis. Magnetic beads were used to deplete or enrich specific cell subpopulations from donor spleens. Depletion of $CD19^+$ B cells, T cells, or NK cells had no effect on CpG-induced arthritis. However, removal of $CD11c^+$ dendritic cells resulted in a complete abrogation of the suppressive activity of the transferred spleen cell population. Similarly, the transfer of only 5×10^5 $CD11c^+$ enriched cells from suppressive ODN treated mice to normal recipients conferred resistance to CpG-induced arthritis.

Figs. 10A through 10F are graphs showing the factors contributing to the suppression of CpG-induced immune activation. Fig. 10A is a graph showing that mammalian DNA suppresses CpG DNA-induced immune activation. Fig. 10B is a graph showing that the telomeric TTAGGG repetitive motif is suppressive. Fig. 10C is a graph showing that the suppressive motif is active in *trans* and *cis* conformations. Fig. 10D is a graph showing that suppressive ODNs selectively block CpG DNA-induced immune activation. Fig. 11E is a graph showing that Poly Gs are critical for suppression. Fig. 10F is a graph showing that G-tetrad forming non-telomere sequences are also suppressive.

Fig. 11 is a pair of graphs showing that G-tetrad-forming suppressive ODNs selectively suppress CpG-induced immune activation. Fig. 11A is a graph showing that oligonucleotides (ODNs) containing suppressive motifs inhibit CpG-induced immune activation in a dose dependent fashion. Fig. 11B is a graph showing G-tetrad formation and suppressive activity of phosphorothioate and 7-deaza guanosine (DG) modified ODNs.

Fig. 12 is a graph showing the effect of suppressive ODN on CpG DNA and Concavalin A induced IFN γ production. BALB/c spleen cells were stimulated with 1 μ M CpG ODN (ODN1555, ODN1466), 50 μ g/ml of bacterial DNA, or 5 μ g/ml Con A. The response of these cultures was compared to cells co-stimulated with 1 μ M of control ODN1612, suppressive ODN1502 or suppressive ODNH154. The number of IFN γ secreting cells was determined by ELISpot after 18 hours. Data represent the average + standard deviation (SD) of triplicate cultures. The experiment was repeated three times with similar results.

Fig. 13 is a graph showing the concentration effects of suppressive ODN. BALB/c spleen cells were stimulated with 1 μ M CpG ODN1555 or ODN1466 plus increasing amounts of suppressive ODN1502 or ODNH154. Cytokine levels in culture supernatants were measured by Enzyme-Linked Immunosorbent Assay (ELISA) after 24 hours. Results represent the mean + SD of 4 different experiments.

Fig. 14 is a graph showing the kinetics of suppressive ODN. BALB/c spleen cells were stimulated with 1 μ M CpG ODN1555. At various times, 1 μ M suppressive ODN1502 was added. Cytokine levels in culture supernatants were measured by ELISA after 24 hours. Results represent the mean of two independent experiments.

Fig. 15 is a graph showing the effect of removing CpG ODN from cultured cells. 1 μ M of CpG ODN1555 was added to BALB/c spleen cells at time (T) = 0.

The cells were washed free of this ODN after various incubation periods. IFN γ and IL-12 levels in culture supernatants were measured by ELISA after 24 hours. Results represent the average \pm SD of duplicate cultures. Similar results were obtained in studies of CpG ODN1466.

5

Fig. 16 is a graph showing that suppressive ODN do not block the binding or uptake of CpG ODN. BALB/c spleen cells were incubated with 1 μ M of CpG ODN1555 (black bar) plus 1 μ M of suppressive ODN1502 (grey bar) or control ODN1612 (white bar). The percent of cells that bound or internalized the CpG ODN was determined by FACS. Similar results were obtained using CpG ODN1466, suppressive ODNH154 and control ODN1471.

10

Fig. 17 is a schematic diagram of the timing of type II collagen injection and ODN administration for DBA/1 LacJ mice. Ten to twenty DBA/1 LacJ mice per group were injected with type II collagen in complete Freund's adjuvant (CII/CFA) on day 0, and with type II collagen in incomplete Freund's adjuvant (CII/IFA) on day 21 to induce arthritis. The study groups included animals treated with 200 μ g of suppressive ODN A151, control ODN 1612 or PBS on days -3, 0, 3, 7, 10, 14, 18 and 21. The incidence of arthritis and clinical score were monitored twice weekly. Antigen-specific humoral and cellular immune responses, and local expression of pro-inflammatory cytokines, were also investigated.

20

Fig. 18 is a pair of graphs showing that treatment with ODN A151 significantly reduced both the percentage of mice that developed arthritis (Figure 18A), and the arthritis clinical score (Figure 18B). Standard curves were constructed by serial dilutions of a mixture of sera from arthritic mice. A single asterisk (*) indicates that $p < 0.05$; a double asterisk (**) indicates that $p < 0.01$, as compared with PBS-control mice.

25

Fig. 19 is a graph showing that production of anti-type 2 collagen (CII) antibody is suppressed by A151 treatment. Sera were collected on day 35 and assayed for IFN γ by ELISA assay, as described above. Standard curves were

30

constructed by serial dilutions of a mixture of sera from arthritic mice. A single asterisk (*) indicates that $p < 0.05$; a double asterisk (**) indicates that $p < 0.01$, as compared with PBS-control mice.

5 Fig. 20 is a pair of graphs showing that production of anti-CII antibody is suppressed by A151 treatment. Spleen cells from naive, PBS or A151-treated mice were isolated on day 22 (Figure 20A) or 35 (Figure 20B). Cells were stimulated *in vitro* with 50 µg/ml of CII for 72 hours and culture supernatants were assayed for IFN-gamma detection. Each group represents results from six mice (two separate
10 experiments). A single asterisk (*) indicates that $p < 0.05$; a double asterisk (**) indicates that $p < 0.01$, as compared with naive or PBS-control mice.

15 Fig. 21 is a digital image of a gel showing that *in vivo* (local) expression of proinflammatory cytokine is also suppressed by treatment with ODN A151. The hind paws of treated animals were removed on day 35. Total RNA was extracted from tissue homogenates, and mRNA of the pro-inflammatory cytokine IL-1 β was monitored by RT-PCR. Each group contains three mice.

BRIEF DESCRIPTION OF THE SEQUENCE LISTING

- 20 SEQ ID NOs 1-25 are suppressive ODN sequences.
 SEQ ID NOs 28, 29, and 31 are control ODN sequences.
 SEQ ID NOs 26, 27, and 30 are immunostimulatory CpG sequences.
 SEQ ID NOs 32-33 are TNFα primers.
 SEQ ID NOs 34-35 are β-actin primers.

25

DETAILED DESCRIPTION OF SEVERAL EMBODIMENTS

I. Abbreviations

A: adenine

Ab: antibody

30 C: cytosine

- CD:** circular dichroism
- CII:** type II collagen
- CII/CFA:** type II collagen in complete Freund's adjuvant
- CII/IFA:** type II collagen in incomplete Freund's adjuvant
- 5 **CpG ODN:** an oligodeoxynucleotide including a CpG motif.
- DC:** dendritic cell
- DG:** deaza guanosine
- ELISA:** Enzyme-Linked Immunosorbent Assay
- FCS:** fetal calf serum
- 10 **G:** guanine
- GI:** gastrointestinal
- GU:** genitourinary
- h:** hour
- IFN- α :** interferon alpha
- 15 **IFN- γ :** interferon gamma
- IL-10:** interleukin 10
- LPS:** lipopolysaccharide
- μ g:** microgram
- mm:** millimeter
- 20 **mRNA:** messenger ribonucleic acid.
- ODN:** oligodeoxynucleotide
- PBS:** phosphate buffered saline
- Pu:** purine
- Py:** pyrimidine
- 25 **s.c.:** subcutaneous
- SD:** standard deviation
- SE:** standard error
- T:** thymine
- 30

II. Terms

Unless otherwise noted, technical terms are used according to conventional usage. Definitions of common terms in molecular biology may be found in Benjamin Lewin, *Genes V*, published by Oxford University Press, 1994 (ISBN 0-19-854287-9); Kendrew *et al.* (eds.), *The Encyclopedia of Molecular Biology*, published 5 by Blackwell Science Ltd., 1994 (ISBN 0-632-02182-9); and Robert A. Meyers (ed.), *Molecular Biology and Biotechnology: a Comprehensive Desk Reference*, published by VCH Publishers, Inc., 1995 (ISBN 1-56081-569-8).

Unless otherwise explained, all technical and scientific terms used herein have 10 the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. The singular terms "a," "an," and "the" include plural referents unless context clearly indicates otherwise. Similarly, the word "or" is intended to include "and" unless the context clearly indicates otherwise. It is further to be understood that all base sizes or amino acid sizes, and all molecular weight or 15 molecular mass values, given for nucleic acids or polypeptides are approximate, and are provided for description. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present disclosure, suitable methods and materials are described below. In case of conflict, the present specification, including explanations of terms, will control. In addition, 20 the materials, methods, and examples are illustrative only and not intended to be limiting.

In order to facilitate review of the various embodiments of the disclosure, the following explanations of specific terms are provided:

25 5' and 3': DNA molecules are said to have "5' ends" and "3' ends" because mononucleotides are reacted to make oligonucleotides in a manner such that the 5' phosphate of one mononucleotide pentose ring is attached to the 3' oxygen of its neighbor in one direction via a phosphodiester linkage. Therefore, an end of an oligonucleotide is referred to as the "5' end" if its 5' phosphate is not linked to the 30 3' oxygen of a mononucleotide pentose ring. An end of an oligonucleotide is referred to as the "3' end" if its 3' oxygen is not linked to a 5' phosphate of another mononucleotide pentose ring. As used herein, a nucleic acid sequence, even if

internal to a larger oligonucleotide, also may be said to have 5' and 3' ends. In either a linear or circular DNA molecule, discrete elements are referred to as being "upstream" or 5' of the "downstream" or 3' elements. This terminology reflects that transcription proceeds in a 5' to 3' direction along the DNA strand. The promoter and enhancer elements which direct transcription of a linked gene are generally located 5' or upstream of the coding region. However, enhancer elements can exert their effect even when located 3' of the promoter element and the coding region. Transcription termination and polyadenylation signals are located 3' or downstream of the coding region.

10 **Animal:** Living multi-cellular vertebrate organisms, a category that includes, for example, mammals and birds. The term mammal includes both human and non-human mammals. Similarly, the term "subject" includes both human and veterinary subjects.

15 **Anti-inflammatory or anti-arthritis agent:** A medication that, as well as having pain-relieving (analgesic) effects, has the effect of reducing inflammation when used over a period of time. Anti-inflammatory or anti-arthritis agents include both steroids and non-steroidal anti-inflammatory agents. Anti-inflammatory or anti-arthritis agents include, but are not limited to cortisone, prednisone, celecoxib, choline magnesium trisalicylate, diclofenac, diclofenac potassium, diclofenac XR, 20 diflunisal, etodolac, etodolac ER, fenoprofen, flurbiprofen oral, ibuprofen, indomethacin, indomethacin SR, indomethacin suppositories, ketoprofen, ketoprofen ER, meclofenamate, meloxicam, nabumetone, naproxen, naproxen CR, naproxen ER, oxaprozin, piroxicam, rofecoxib, salsalate, sulindac, and tolmetin sodium.

25 **Antigen:** A compound, composition, or substance that can stimulate an immune response such as the production of antibodies or a T-cell response in an animal, including compositions that are injected or absorbed into an animal. An antigen reacts with the products of specific humoral or cellular immunity, including those induced by heterologous immunogens. The term "antigen" includes all related antigenic epitopes.

30 **Antisense, Sense, and Antigene:** Double-stranded DNA (dsDNA) has two strands, a 5' -> 3' strand, referred to as the plus strand, and a 3' -> 5' strand (the reverse complement), referred to as the minus strand. Because RNA polymerase

adds nucleic acids in a 5' → 3' direction, the minus strand of the DNA serves as the template for the RNA during transcription. Thus, the RNA formed will have a sequence complementary to the minus strand and identical to the plus strand (except that U is substituted for T).

5 Antisense molecules are molecules that are specifically hybridizable or specifically complementary to either RNA or the plus strand of DNA. Sense molecules are molecules that are specifically hybridizable or specifically complementary to the minus strand of DNA. Antigene molecules are either antisense or sense molecules directed to a dsDNA target. In one embodiment, an
10 antisense molecule specifically hybridizes to a target mRNA and inhibits transcription of the target mRNA.

Arthritis: Arthritis is an inflammatory disease that affects the synovial membranes of one or more joints in the body. It is the most common type of joint disease, and it is characterized by the inflammation of the joint. The disease is
15 usually oligoarticular (affects few joints), but may be generalized. The joints commonly involved include the hips, knees, lower lumbar and cervical vertebrae, proximal and distal interphangeal joints of the fingers, first carpometacarpal joints, and first tarsometatarsal joints of the feet.

 One type of arthritis is reactive arthritis, which is an acute nonpurulent
20 arthritis secondary to a urinary tract or gastrointestinal infection with a variety of microorganisms, including *Chlamydia trachomatis*, *Yersinia*, *Salmonella*, *Shigella*, and *Campylobacter*. Microbial components are found in the affected joints. The arthritis appears abruptly and tends to involve the knees and ankles, but sometimes involves the wrists, fingers, and/or toes. Untreated, the arthritis lasts for about a
25 year, then generally abates and only rarely is accompanied by ankylosing spondylitis. Despite evidence of disease being triggered by bacterial infection, viable bacteria are rarely present in affected joints and antibiotic treatment seldom provides relief.

 Another type of arthritis is rheumatoid arthritis. Rheumatoid arthritis is a
30 chronic, systemic, inflammatory disease that affects the synovial membranes of multiple joints in the body. Because the disease is systemic, there are many extra-articular features of the disease as well. For example, neuropathy, scleritis,

lymphadenopathy, pericarditis, splenomegaly, arteritis, and rheumatoid nodules are frequent components of the disease. In most cases of rheumatoid arthritis, the subject has remissions and exacerbations of the symptoms. Rheumatoid arthritis is considered an autoimmune disease that is acquired and in which genetic factors appear to play a role.

Autoimmune disorder: A disorder in which the immune system produces an immune response (for example, a B cell or a T cell response) against an endogenous antigen, with consequent injury to tissues. For example, rheumatoid arthritis is an autoimmune disorder, as are Hashimoto's thyroiditis, pernicious anemia, Addison's disease, type I diabetes, systemic lupus erythematosus, dermatomyositis, Sjogren's syndrome, dermatomyositis, lupus erythematosus, multiple sclerosis, myasthenia gravis, Reiter's syndrome, and Grave's disease, among others.

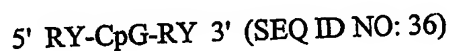
CD value: The formation of G-tetrads yields a complex with different physical properties than the individual oligonucleotides. Spectroscopically, this is manifested by an increase in circular dichroism (CD), and an increase in peak absorbance to the 260-280 nm wavelength owing to the formation of secondary structures. Thus, a convenient method for identifying oligonucleotides that form G-tetrads is to study their CD values. An increase in peak ellipticity values to greater than 2.0 is typical of a G-tetrad forming oligonucleotide. The higher the ellipticity value, the greater the tetrad-forming capacity of the oligonucleotide.

CpG or CpG motif: A nucleic acid having a cytosine followed by a guanine linked by a phosphate bond in which the pyrimidine ring of the cytosine is unmethylated. The term "methylated CpG" refers to the methylation of the cytosine on the pyrimidine ring, usually occurring the 5-position of the pyrimidine ring. A CpG motif is a pattern of bases that include an unmethylated central CpG surrounded by at least one base flanking (on the 3' and the 5' side of) the central CpG. Without being bound by theory, the bases flanking the CpG confer part of the activity to the CpG oligodeoxynucleotide. A CpG oligonucleotide is an oligonucleotide that is at least about ten nucleotides in length and includes an unmethylated CpG. CpG oligonucleotides include both D and K type oligodeoxynucleotides (see below). CpG oligodeoxynucleotides are single-stranded.

The entire CpG oligodeoxynucleotide can be unmethylated or portions may be unmethylated. In one embodiment, at least the C of the 5' CpG 3' is unmethylated.

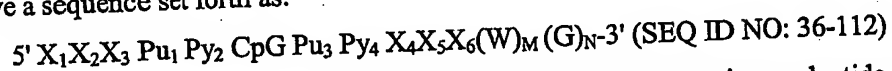
Cytokine: Proteins made by cells that affect the behavior of other cells, such as lymphocytes. In one embodiment, a cytokine is a chemokine, a molecule that affects cellular trafficking.

D Type Oligodeoxynucleotide (D ODN): An oligodeoxynucleotide including an unmethylated CpG motif that has a sequence represented by the formula:



wherein the central CpG motif is unmethylated, R is A or G (a purine), and Y is C or T (a pyrimidine). D-type oligodeoxynucleotides include an unmethylated CpG dinucleotide. Inversion, replacement or methylation of the CpG reduces or abrogates the activity of the D oligodeoxynucleotide.

In one embodiment, a D type ODN is at least about 16 nucleotides in length and includes a sequence represented by Formula III of PCT Application No. PCT/US02/30532, which is incorporated by reference herein. The oligonucleotides have a sequence set forth as:



wherein the central CpG motif is unmethylated, Pu is a purine nucleotide, Py is a pyrimidine nucleotide, X and W are any nucleotide, M is any integer from 0 to 10, and N is any integer from 4 to 10. Generally D ODNs can stimulate a cellular response. For example, D ODNs stimulate natural killer cells and the maturation of dendritic cells.

Epitope: An antigenic determinant. These are particular chemical groups or peptide sequences on a molecule that are antigenic, for example, that elicit a specific immune response. An antibody binds a particular antigenic epitope.

Functionally Equivalent: Sequence alterations, for example in a suppressive ODN, that yield the same results as described herein. Such sequence alterations can include, but are not limited to, deletions, base modifications, mutations, labeling, and insertions.

G-tetrad: G-tetrads are G-rich DNA segments that can accommodate complex secondary and/or tertiary structures (see Fig. 1). A G-tetrad involves the planar association of four Gs in a cyclic Hoogsteen hydrogen bonding arrangement (this involves non-Watson Crick base-pairing). In general, either a run of two or
5 more contiguous Gs or a hexameric region in which >50% of the bases are Gs, is needed for an ODN to form a G-tetrad. The longer the run of contiguous Gs, and the higher the G content of the ODN, the higher the likelihood of G-tetrad formation, as reflected by higher CD or ellipticity values.

Oligonucleotides that form G-tetrads can also form higher-level aggregates
10 that are more easily recognized and taken up by immune cells, for example, through scavenger receptors or by nucleolin.

Guanosine-rich sequence: A hexameric region of a nucleotide sequence in which >50% of the bases are Gs.

Immediately adjacent: Two nucleic acid sequences are "immediately
15 adjacent" if a spacer of 0-9 nucleotides is included between the nucleic acid sequences. In one example, one nucleic acid sequence includes an immunostimulatory CpG motif and the other nucleic acid sequence is a suppressive nucleic acid sequence. Thus an immunostimulatory CpG motif and the suppressive ODN sequence are immediately adjacent if they are separated by less than 9
20 nucleotides.

Immunostimulatory CpG ODN: An oligodeoxynucleotide, which contains a cytosine, guanine dinucleotide sequence and stimulates (for example, has a mitogenic effect) vertebrate immune cells. The cytosine, guanine is unmethylated. Both D and K type CpG ODNs are immunostimulatory (see in Verthelyi *et al.*, *J.*
25 *Immunol.* 166:2372-2377, 2001, which is herein incorporated by reference).

Immunosuppressive agent: A molecule, such as a chemical compound, small molecule, steroid, nucleic acid molecule, or other biological agent, that can decrease an immune response such as an inflammatory reaction. Immunosuppressive agents include, but are not limited to an agent of use in treating
30 arthritis (anti-arthritis agent). Specific, non-limiting examples of immunosuppressive agents are non-steroidal anti-inflammatory agents, cyclosporine

A, FK506, and anti-CD4. In additional examples, the agent is a biological response modifier, such as Kineret® (anakinra), Enbrel® (etanercept), or Remicade® (infliximab), a disease-modifying antirheumatic drug (DMARD), such as Arava® (leflunomide), a nonsteroidal anti-inflammatory drug (NSAID), specifically a Cyclo-
 5 Oxygenase-2 (COX-2) inhibitor, such as Celebrex® (celecoxib) and Vioxx® (rofecoxib), or another product, such as Hyalgan® (hyaluronan) and Synvisc® (hylan G-F20).

Immune response: A response of a cell of the immune system, such as a B cell or T cell to a stimulus. In one embodiment, the response is specific for a
 10 particular antigen (an "antigen-specific response").

Infectious agent: An agent that can infect a subject, including, but not limited to, viruses, bacteria, and fungi.

Examples of infectious virus include: *Retroviridae* (for example, human immunodeficiency viruses, such as HIV-1 (also referred to as HTLV-III, LAV or
 15 HTLV-III/LAV, or HIV-III; and other isolates, such as HIV-LP; *Picornaviridae* (for example, polio viruses, hepatitis A virus; enteroviruses, human coxsackie viruses, rhinoviruses, echoviruses); *Calciviridae* (such as strains that cause gastroenteritis); *Togaviridae* (for example, equine encephalitis viruses, rubella viruses); *Flaviridae* (for example, dengue viruses, encephalitis viruses, yellow fever viruses);
 20 *Coronaviridae* (for example, coronaviruses); *Rhabdoviridae* (for example, vesicular stomatitis viruses, rabies viruses); *Filoviridae* (for example, ebola viruses); *Paramyxoviridae* (for example, parainfluenza viruses, mumps virus, measles virus, respiratory syncytial virus); *Orthomyxoviridae* (for example, influenza viruses); *Bunyaviridae* (for example, Hantaan viruses, bunya viruses, phleboviruses and
 25 Nairo viruses); *Arena viridae* (hemorrhagic fever viruses); *Reoviridae* (for example, reoviruses, orbiviruses and rotaviruses); *Birnaviridae*; *Hepadnaviridae* (Hepatitis B virus); *Parvoviridae* (parvoviruses); *Papovaviridae* (papilloma viruses, polyoma viruses); *Adenoviridae* (most adenoviruses); *Herpesviridae* (herpes simplex virus (HSV) 1 and HSV-2, varicella zoster virus, cytomegalovirus (CMV), herpes
 30 viruses); *Poxviridae* (variola viruses, vaccinia viruses, pox viruses); and *Iridoviridae* (such as African swine fever virus); and unclassified viruses (for example, the etiological agents of Spongiform encephalopathies, the agent of delta hepatitis

(thought to be a defective satellite of hepatitis B virus), the agents of non-A, non-B hepatitis (class 1=internally transmitted; class 2=parenterally transmitted (for example, Hepatitis C); Norwalk and related viruses, and astroviruses).

Examples of infectious bacteria include: *Helicobacter pylori*, *Borelia burgdorferi*, *Legionella pneumophila*, *Mycobacteria* sps (such as *M. tuberculosis*, *M. avium*, *M. intracellulare*, *M. kansaii*, *M. gordonae*), *Staphylococcus aureus*, *Neisseria gonorrhoeae*, *Neisseria meningitidis*, *Listeria monocytogenes*, *Streptococcus pyogenes* (Group A *Streptococcus*), *Streptococcus agalactiae* (Group B *Streptococcus*), *Streptococcus (viridans* group), *Streptococcus faecalis*, *Streptococcus bovis*, *Streptococcus (anaerobic* sps.), *Streptococcus pneumoniae*, pathogenic *Campylobacter* sp., *Enterococcus* sp., *Haemophilus influenzae*, *Bacillus anthracis*, *Corynebacterium diphtheriae*, *Corynebacterium* sp., *Erysipelothrix rhusiopathiae*, *Clostridium perfringens*, *Clostridium tetani*, *Enterobacter aerogenes*, *Klebsiella pneumoniae*, *Pasturella multocida*, *Bacteroides* sp., *Fusobacterium nucleatum*, *Streptobacillus moniliformis*, *Treponema pallidum*, *Treponema pertenuis*, *Leptospira*, and *Actinomyces israeli*.

Examples of infectious fungi include, but are not limited to, *Cryptococcus neoformans*, *Histoplasma capsulatum*, *Coccidioides immitis*, *Blastomyces dermatitidis*, *Chlamydia trachomatis*, and *Candida albicans*.

Other infectious organisms (such as protists) include: *Plasmodium falciparum* and *Toxoplasma gondii*.

Inflammatory arthropathy: An inflammatory arthropathy is an inflammatory disease affecting one or more joints, such as an inflammatory disease that affects the synovial membranes of one or more joints. Inflammatory arthropathies include, for example, arthritis, ankylosing spondylitis, Reiter's syndrome, psoriatic arthropathy, enteropathic spondylitis, juvenile arthropathy, and reactive arthropathy.

Isolated: An "isolated" biological component (such as a nucleic acid, peptide or protein) has been substantially separated, produced apart from, or purified away from other biological components in the cell of the organism in which the component naturally occurs, for example, other chromosomal and extrachromosomal DNA and RNA, and proteins. Nucleic acids, peptides and

proteins which have been "isolated" thus include nucleic acids and proteins purified by standard purification methods. The term also embraces nucleic acids, peptides and proteins prepared by recombinant expression in a host cell as well as chemically synthesized nucleic acids.

- 5 **K Type Oligodeoxynucleotide (K ODN):** An oligodeoxynucleotide including an unmethylated CpG motif that has a sequence represented by the formula:



- 10 wherein the central CpG motif is unmethylated, Q is T, G or A, W is A or T, and N₁, N₂, N₃, N₄, N₅, and N₆ are any nucleotides. In one embodiment, Q is a T. Generally K ODNs can stimulate a humoral response. For example, K ODNs stimulate the production of IgM. K type CpG ODNs have been previously described (see U.S. Patent Nos. 6,194,388; 6,207,646; 6,214,806; 6,218,371; 6,239,116, 6,339,068; 6,406,705, and 6,429,199, which are herein incorporated by reference).

- 15 **Leukocyte:** Cells in the blood, also termed "white cells," that are involved in defending the body against infective organisms and foreign substances. Leukocytes are produced in the bone marrow. There are 5 main types of white blood cell, subdivided between 2 main groups: polymorphonuclear leukocytes (neutrophils, eosinophils, basophils) and mononuclear leukocytes (monocytes and lymphocytes).
20 When an infection is present, the production of leukocytes increases.

Maturation: The process in which an immature cell, such as dendritic cell, changes in form or function to become a functional mature cell, such as an antigen presenting cell (APC).

- 25 **Nucleic acid:** A deoxyribonucleotide or ribonucleotide polymer in either single or double stranded form, and unless otherwise limited, encompasses known analogues of natural nucleotides that hybridize to nucleic acids in a manner similar to naturally occurring nucleotides.

- 30 **Oligonucleotide or oligo:** Multiple nucleotides (for example, molecules comprising a sugar, for example, ribose or deoxyribose) linked to a phosphate group and to an exchangeable organic base, which is either a substituted pyrimidine (Py) (for example, cytosine (C), thymine (T) or uracil (U)) or a substituted purine (Pu) (for example, adenine (A) or guanine (G)). The term "oligonucleotide" as used

herein refers to both oligoribonucleotides (ORNs) and oligodeoxyribonucleotides (ODNs). The term "oligonucleotide" also includes oligonucleosides (an oligonucleotide minus the phosphate) and any other organic base polymer. Oligonucleotides can be obtained from existing nucleic acid sources (for example, genomic or cDNA), but are preferably synthetic (for example, produced by oligonucleotide synthesis).

A "stabilized oligonucleotide" is an oligonucleotide that is relatively resistant to *in vivo* degradation (for example via an *exo*- or *endo*-nuclease). In one embodiment, a stabilized oligonucleotide has a modified phosphate backbone. One specific, non-limiting example of a stabilized oligonucleotide has a phosphorothioate modified phosphate backbone (wherein at least one of the phosphate oxygens is replaced by sulfur). Other stabilized oligonucleotides include: nonionic DNA analogs, such as alkyl- and aryl- phosphonates (in which the charged phosphonate oxygen is replaced by an alkyl or aryl group), phosphodiester and alkylphosphotriesters, in which the charged oxygen moiety is alkylated. Oligonucleotides which contain a diol, such as tetraethyleneglycol or hexaethyleneglycol, at either or both termini have also been shown to be substantially resistant to nuclease degradation.

An "immunostimulatory oligonucleotide," "immunostimulatory CpG containing oligodeoxynucleotide," or "CpG ODN," refers to an oligodeoxynucleotide, which contains a cytosine, guanine dinucleotide sequence and stimulates (for example, has a mitogenic effect) vertebrate immune cells. The cytosine, guanine is unmethylated.

An "oligonucleotide delivery complex" is an oligonucleotide associated with (for example, ionically or covalently bound to; or encapsulated within) a targeting means (for example, a molecule that results in a higher affinity binding to a target cell (for example, B-cell or natural killer (NK) cell) surface and/or increased cellular uptake by target cells). Examples of oligonucleotide delivery complexes include oligonucleotides associated with: a sterol (for example, cholesterol), a lipid (for example, cationic lipid, virosome or liposome), or a target cell specific binding agent (for example, a ligand recognized by a target cell specific receptor). Preferred

complexes must be sufficiently stable *in vivo* to prevent significant uncoupling prior to internalization by the target cell. However, the complex should be cleavable or otherwise accessible under appropriate conditions within the cell so that the oligonucleotide is functional. (Gursel, *J. Immunol.* 167: 3324, 2001)

5 **Parenteral:** Administered outside of the intestine, for example, not via the alimentary tract. Generally, parenteral formulations are those that will be administered through any possible mode except ingestion. This term especially refers to injections, whether administered intravenously, intrathecally, intramuscularly, intraperitoneally, intra-articularly, or subcutaneously, and various
10 surface applications including intranasal, intradermal, and topical application.

Pharmaceutical agent or drug: A chemical compound or composition capable of inducing a desired therapeutic or prophylactic effect when properly administered to a subject. Pharmaceutical agents include, but are not limited to, chemotherapeutic agents and anti-infective agents.

15 **Pharmaceutically acceptable carriers:** The pharmaceutically acceptable carriers useful in this disclosure are conventional. *Remington's Pharmaceutical Sciences*, by E. W. Martin, Mack Publishing Co., Easton, PA, 15th Edition (1975), describes compositions and formulations suitable for pharmaceutical delivery of the fusion proteins herein disclosed.

20 In general, the nature of the carrier will depend on the particular mode of administration being employed. For instance, parenteral formulations usually comprise injectable fluids that include pharmaceutically and physiologically acceptable fluids such as water, physiological saline, balanced salt solutions, aqueous dextrose, glycerol or the like as a vehicle. For solid compositions (for
25 example, powder, pill, tablet, or capsule forms), conventional non-toxic solid carriers can include, for example, pharmaceutical grades of mannitol, lactose, starch, or magnesium stearate. In addition to biologically-neutral carriers, pharmaceutical compositions to be administered can contain minor amounts of non-toxic auxiliary substances, such as wetting or emulsifying agents, preservatives, and pH buffering
30 agents and the like, for example sodium acetate or sorbitan monolaurate.

Preventing or treating a disease: "Preventing" a disease refers to inhibiting the full development of a disease, for example in a person who is known

to have a predisposition to a disease such as an autoimmune disorder. An example of a person with a known predisposition is someone with a history of diabetes in the family, or who has been exposed to factors that predispose the subject to a condition, such as lupus or arthritis. "Treatment" refers to a therapeutic intervention that
5 ameliorates a sign or symptom of a disease or pathological condition after it has begun to develop.

Purified: The term purified does not require absolute purity; rather, it is intended as a relative term. Thus, for example, a purified peptide preparation is one in which the peptide or protein is more enriched than the peptide or protein is in its
10 natural environment within a cell. Preferably, a preparation is purified such that the protein or peptide represents at least 50% of the total peptide or protein content of the preparation.

Suppressive ODN: DNA molecules of at least eight nucleotides in length, wherein the oligodeoxynucleotide forms a G-tetrad, and has a CD value of greater
15 than about 2.9. In a suppressive ODN the number of guanosines is at least two. In one embodiment, a suppressive ODN inhibits immune activation caused by CpG DNA when administered prior to, concurrently with, or after the administration of a CpG ODN at least about 8 nucleotides in length.

Therapeutic agent: Used in a generic sense, it includes treating agents,
20 prophylactic agents, and replacement agents.

Therapeutically effective amount of [a compound]: A quantity of a specified compound sufficient to achieve a desired effect in a subject being treated. For instance, this can be the amount of a suppressive ODN necessary to suppress
25 CpG-induced immune cell activation in a subject, or a dose sufficient to prevent advancement, or to cause regression of a disease, or which is capable of relieving symptoms caused by a disease, such as pain or swelling.

The therapeutically effective amount of a suppressive ODN can be administered systemically or locally. In addition, a therapeutically effective amount of a suppressive ODN can be administered in a single dose, or in several doses, for
30 example daily, during a course of treatment. However, the therapeutically effective amount of the ODN will be dependent on the preparation applied, the subject being treated, the severity and type of the affliction, and the manner of administration of

the compound. For example, a therapeutically effective amount of a suppressive ODN can vary from about 0.01 mg/kg body weight to about 1 g/kg body weight in some embodiments, or from about 0.01 mg/kg to about 60 mg/kg of body weight, based on efficacy.

- 5 **Therapeutically effective dose:** A dose sufficient to prevent advancement, or to cause regression of the disease, or which is capable of relieving symptoms caused by the disease, such as pain or swelling.

10 III. *Description of Several Embodiments*

10 A. *Suppressive Oligodeoxynucleotides and Guanosine-quadruplexes (G-tetrads)*

The present disclosure relates to a class of DNA motifs that selectively inhibits or suppresses immune activation. Optimal activity is observed using multimers of these motifs, which are rich in G bases and capable of forming G-
15 quadruplexes (G-tetrads). G-tetrads are G-rich DNA segments that can accommodate complex secondary and/or tertiary structures (see Fig. 1). The suppressive ODNs of the disclosure are highly specific (for example, are neither toxic nor non-specifically immunosuppressive), and are useful for inhibiting an immune response. In one embodiment, a suppressive ODN is of use for blocking an
20 immune response, such as an autoimmune response.

A G-tetrad involves the planar association of four Gs in a cyclic Hoogsteen hydrogen bonding arrangement (this involves non-Watson Crick base-pairing). In general, either a run of two or more contiguous Gs or a hexameric region in which >50% of the bases are Gs, is needed for an ODN to form a G-tetrad. The longer the
25 run of continuous Gs, and the higher the G content of the ODN, the higher the likelihood of G-tetrad formation, as reflected by higher ellipticity values. Oligonucleotides that form G-tetrads can also form higher-level aggregates that are more easily recognized and taken up by immune cells, for example, through scavenger receptors or by nucleolin.

30 The formation of G-tetrads yields a complex with different physical properties than the individual oligonucleotides. Spectroscopically, this is manifested by an increase in circular dichroism (CD), and an increase in peak absorbance to the

260-280 nm wavelength owing to the formation of secondary structures. Thus, a convenient method for identifying oligonucleotides that form G-tetrads is to study their CD values. An increase in peak ellipticity values to greater than 2.0 is typical of a G-tetrad forming oligonucleotide. For instance, G-tetrad-forming ODNs can have CD values of about 2.2, 2.4, 2.6, 2.8, 3.0, 3.2, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, or higher. The higher the ellipticity value, the greater the tetrad-forming capacity of the oligonucleotide, so an ODN with a CD value of about 8.5 is typically more suppressive than an ODN with a CD value of about 2.9.

In some embodiments, the ODN is from about 8 to about 100 nucleotides in length. In particular examples, the ODN is from about 10 to about 30 nucleotides in length. Optionally, the suppressive ODN has multiple guanosine-rich sequences, for example, in certain embodiments the ODN has from about two to about 20 guanosine-rich sequences, or, more particularly, from about two to about four guanosine-rich sequences.

In one embodiment, the suppressive ODNs have a sequence comprising at least one of the human telomere-derived TTAGGG suppressive motifs (see Example 1). In some examples, the ODN has at least one TTAGGG motif, and in certain examples, the ODN has multiple TTAGGG motifs. For example, in particular examples, the ODN has from about two to about 20 TTAGGG motifs, or from about two to about four TTAGGG motifs. In this embodiment, suppressive ODNs containing multiple TTAGGG repeats are the most suppressive. Single TTAGGG motifs are suppressive only when incorporated into larger ODNs with greater than 10 bases.

Suppression of CpG-induced immune activation requires a G-tetrad-forming sequence that imposes the two-dimensional structure necessary for G-tetrad formation. Examples of suppressive ODN include, but are not limited to, those shown in Fig. 9. However, any oligonucleotide capable of forming G-tetrads may be used to suppress CpG DNA-induced immune activation. In particular examples, the ODN includes selected from the group consisting of SEQ ID NO: 1, SEQ ID NO: 2, SEQ ID NO: 3, SEQ ID NO: 4, SEQ ID NO: 5, SEQ ID NO: 6, SEQ ID NO: 7, SEQ ID NO: 8, SEQ ID NO: 9, SEQ ID NO: 10, SEQ ID NO: 11, SEQ ID NO: 12, SEQ ID NO: 13, SEQ ID NO: 14, SEQ ID NO: 15, SEQ ID NO: 16, SEQ ID

NO: 17, SEQ ID NO: 18, SEQ ID NO: 19, SEQ ID NO: 20, SEQ ID NO: 21, SEQ ID NO: 22, SEQ ID NO: 23, SEQ ID NO: 24, and SEQ ID NO: 25.

Furthermore, in particular embodiments the ODN is modified to prevent degradation and increase stability. In one embodiment, suppressive ODNs can include modified nucleotides to confer resistance to degradation. Thus, because phosphorothioate-modified nucleotides confer resistance to exonuclease digestion, a suppressive ODN can be "stabilized" by incorporating phosphorothioate-modified nucleotides.

In some embodiments, the ODN has a phosphate backbone modification, and in particular examples, the phosphate backbone modification is a phosphorothioate backbone modification. In one embodiment, the guanosine-rich sequence and its immediate flanking regions include phosphodiester rather than phosphorothioate nucleotides. In one specific non-limiting example, the sequence TTAGGG includes phosphodiester bases. In some examples, all of the bases in an ODN are phosphodiester bases. In other examples, the ODN is a phosphorothioate/phosphodiester chimera.

As disclosed herein, any suitable modification can be used to render the ODN resistant to degradation *in vivo* (for example, via an *exo*- or *endo*-nuclease). In one specific, non-limiting example, a modification that renders the ODN less susceptible to degradation is the inclusion of nontraditional bases such as inosine and quesine, as well as acetyl-, thio- and similarly modified forms of adenine, cytidine, guanine, thymine, and uridine. Other modified nucleotides include nonionic DNA analogs, such as alkyl or aryl phosphonates (for example, those in which the charged phosphonate oxygen is replaced with an alkyl or aryl group, as set forth in U.S. Patent No. 4,469,863), phosphodiesters and alkylphosphotriesters (for example, those in which the charged oxygen moiety is alkylated, as set forth in U.S. Patent No. 5,023,243 and European Patent No. 0 092 574). ODNs containing a diol, such as tetraethyleneglycol or hexaethyleneglycol, at either or both termini, have also been shown to be more resistant to degradation.

The suppressive ODN of the disclosure can be synthesized by standard methods well known in the art. Most commonly, synthesis is performed on an oligonucleotide synthesizer using the standard cyanoethyl phosphoramidite

chemistry. These include, but are not limited to, phosphodiester, phosphorothioate, peptide nucleic acids, synthetic peptide analogues, and any combination thereof. Those skilled in the art will recognize that any other standard technique may be used to synthesize the suppressive ODN described herein.

5 The suppressive ODN can be included in a single polynucleotide that also includes an immunostimulatory CpG motif, such as a D or a K type oligonucleotide sequence. Generally, if a suppressive ODN sequence and an immunostimulatory ODN sequence are included in the a single polynucleotide, the polynucleotide selectively inhibits or suppresses immune activation.

10 In one example, a polynucleotide that selectively inhibits or suppresses immune activation includes an immunostimulatory CpG motif placed 5' to a suppressive ODN sequence. In this embodiment, a spacer of at least 10 nucleotides is included between the CpG motif and the suppressive ODN sequence in the polynucleotide. The spacer can be any nucleotide sequence of interest, provided it
15 does not include an immunostimulatory CpG motif or the sequence of a suppressive ODN. In one embodiment, the single polynucleotide includes an immunostimulatory CpG motif placed 5' to a suppressive ODN sequence, wherein the immunostimulatory CpG motif is separated from the suppressive ODN sequence by at least 10 nucleotides. Thus, in several examples, the immunostimulatory CpG
20 motif is separated from the suppressive ODN sequence by at least about 10, about 15, about 20, about 25, about 50 or about 100 nucleotides in a single polynucleotide. Spacers of about at least about 100 nucleotides, at least about 500 nucleotides, or at least about about a kilobase can also be utilized.

25 A polynucleotide that selectively inhibits or suppresses immune activation does not include an immunostimulatory CpG motif placed immediately adjacent (5') to a suppressive ODN sequence. Thus, a polynucleotide that selectively inhibits or suppresses immune activation does not include a 5' immunostimulatory CpG motif separated by less than 9 bases from a 3' suppressive ODN sequence.

30 In another example, a polynucleotide that selectively inhibits or suppresses immune activation includes an immunostimulatory CpG motif placed 3' to a suppressive ODN sequence. The immunostimulatory CpG motif can be placed immediately adjacent (3') to a suppressive ODN. In one example, a polynucleotide

that selectively inhibits or suppresses immune activation can include a 3' immunostimulatory CpG motif separated by less than 9 bases from a 5' suppressive ODN. In another example, a spacer of any length can be included between the 3' immunostimulatory CpG motif and the 3' suppressive ODN. In a further example, a spacer of at least one, at least two, at least ten, at least 100, or several kilobases can be inserted between the 3' immunostimulatory CpG motif and the suppressive ODN. Thus, any oligonucleotide including an immunostimulatory CpG motif positioned 3' of a suppressive ODN sequence selectively inhibits or suppresses immune activation. In addition, any double stranded nucleic acid that includes a suppressive ODN sequence and immunostimulatory CpG motif in trans (on opposite strands of the double stranded nucleic acid) selectively inhibits or suppresses immune activation.

In one embodiment, a suppressive ODN is included in a delivery complex. The delivery complex can include the suppressive ODN and a targeting means. Any suitable targeting means can be used. For example, in some embodiments, a suppressive ODN is associated with (for example, ionically or covalently bound to, or encapsulated within) a targeting means (for example, a molecule that results in higher affinity binding to a target cell, such as a B cell). A variety of coupling or cross-linking agents can be used to form the delivery complex, such as protein A, carbodiimide, and N-succinimidyl-3-(2-pyridyldithio) propionate (SPDP). Examples of oligodeoxynucleotide delivery complexes include a suppressive ODN associated with a sterol (for example, cholesterol), a lipid (for example, a cationic lipid, anionic lipid, virosome or liposome), and a target cell specific binding agent (for example, a ligand recognized by target cell specific receptor). Without being bound by theory, the complex is sufficiently stable *in vivo* to prevent significant uncoupling prior to delivery to the target cell. In one embodiment, the delivery complex is cleavable such that the ODN is released in a functional form at the target cells.

30 B. *Pharmaceutical Compositions*

The suppressive ODNs described herein may be formulated in a variety of ways depending on the location and type of disease to be treated. Pharmaceutical

compositions are thus provided for both local (for example, intra-articular) use as well as for systemic use. Therefore, the disclosure includes within its scope pharmaceutical compositions comprising at least one suppressive ODN formulated for use in human or veterinary medicine.

5 Pharmaceutical compositions that include at least one suppressive ODN as described herein as an active ingredient, or that includes both a suppressive ODN and additional agents, such as anti-inflammatory or anti-arthritis factors as active ingredients, can be formulated with an appropriate solid or liquid carrier, depending upon the particular mode of administration chosen. Additional active ingredients
10 include, for example, biological response modifiers, such as Kineret® (anakinra), Enbrel® (etanercept), or Remicade® (infliximab), disease-modifying antirheumatic drugs (DMARDs), such as Arava® (leflunomide), steroids, such as prednisone or cortisone, nonsteroidal anti-inflammatory drugs (NSAIDs), such as celecoxib, choline magnesium trisalicylate, diclofenac, diclofenac potassium, diclofenac XR,
15 diflunisal, etodolac, etodolac ER, fenoprofen, flurbiprofen oral, ibuprofen, indomethacin, indomethacin SR, indomethacin suppositories, ketoprofen, ketoprofen ER, meclofenamate, meloxicam, nabumetone, naproxen, naproxen CR, naproxen ER, oxaprozin, piroxicam, rofecoxib, salsalate, sulindac, or tolmetin sodium, or other products, such as Hyalgan® (hyaluronan) and Synvisc® (hylan G-F20).

20 The pharmaceutically acceptable carriers and excipients useful in this disclosure are conventional. For instance, parenteral formulations usually comprise injectable fluids that are pharmaceutically and physiologically acceptable fluid vehicles such as water, physiological saline, other balanced salt solutions, aqueous dextrose, glycerol or the like. Excipients that can be included are, for instance,
25 proteins, such as human serum albumin or plasma preparations. If desired, the pharmaceutical composition to be administered may also contain minor amounts of non-toxic auxiliary substances, such as wetting or emulsifying agents, preservatives, and pH buffering agents and the like, for example sodium acetate or sorbitan monolaurate.

30 The dosage form of the pharmaceutical composition will be determined by the mode of administration chosen. For instance, in addition to injectable fluids, topical and oral formulations can be employed. Topical preparations can include

eye drops, ointments, sprays and the like. Oral formulations may be liquid (for example, syrups, solutions, or suspensions), or solid (for example, powders, pills, tablets, or capsules). For solid compositions, conventional non-toxic solid carriers can include pharmaceutical grades of mannitol, lactose, starch, or magnesium stearate. Actual methods of preparing such dosage forms are known, or will be apparent, to those of ordinary skill in the art.

The pharmaceutical compositions that comprise a suppressive ODN, in some embodiments, will be formulated in unit dosage form, suitable for individual administration of precise dosages. The amount of active compound(s) administered will be dependent on the subject being treated, the severity of the affliction, and the manner of administration, and is best left to the judgment of the prescribing clinician. Within these bounds, the formulation to be administered will contain a quantity of the active component(s) in amounts effective to achieve the desired effect in the subject being treated.

15

C. *Therapeutic Uses*

A method is disclosed herein for treating or preventing an inflammatory arthropathy in a subject. Inflammatory arthropathies include, but are not limited to reactive arthritis and rheumatoid arthritis. The method includes administering a therapeutically effective amount of the suppressive ODN to a subject having or at risk of developing inflammatory arthropathy, thereby treating or preventing the inflammatory arthropathy. In one embodiment, the suppressive ODN can be administered locally, such as by intra-articular injection. In another embodiment, the suppressive ODN is administered systemically.

25

In order to treat or prevent an inflammatory arthropathy, a therapeutically effective amount of a suppressive ODN (see above) is administered to the subject. In one embodiment, the ODN has a CD value of greater than about 2.9, 3.0, 3.2, 3.4, 3.6, 3.8, 4.0, or 5.0. In some embodiments of the method, the ODN is from about 8 to about 100 nucleotides in length. In particular examples of the method, the ODN is from about 10 to about 30 nucleotides in length. Optionally, the suppressive ODN has multiple guanosine-rich sequences, for example, in certain embodiments of the

30

method, the ODN has from about two to about 20 guanosine-rich sequences, or, more particularly, from about two to about four guanosine-rich sequences.

In some examples of the method, the ODN has at least one TTAGGG motif, and in certain examples, the ODN has multiple TTAGGG motifs. For example, in particular examples of the method, the ODN has from about two to about 20 TTAGGG motifs, or from about two to about four TTAGGG motifs. In particular examples of the method, the ODN has a sequence selected from the group consisting of SEQ ID NO: 1, SEQ ID NO: 2, SEQ ID NO: 3, SEQ ID NO: 4, SEQ ID NO: 5, SEQ ID NO: 6, SEQ ID NO: 7, SEQ ID NO: 8, SEQ ID NO: 9, SEQ ID NO: 10, SEQ ID NO: 11, SEQ ID NO: 12, SEQ ID NO: 13, SEQ ID NO: 14, SEQ ID NO: 15, SEQ ID NO: 16, SEQ ID NO: 17, SEQ ID NO: 18, SEQ ID NO: 19, SEQ ID NO: 20, SEQ ID NO: 21, SEQ ID NO: 22, SEQ ID NO: 23, SEQ ID NO: 24, and SEQ ID NO: 25.

Combinations of these suppressive ODN are also of use. Thus, in one embodiment, more than one suppressive ODN, each with a different nucleic acids sequence, are administered to the subject. In several specific, non-limiting examples, at least two, at least three, or at least four suppressive ODN are administered to the subject.

In another embodiment an additional anti-inflammatory agent is administered in conjunction with a suppressive ODN. The agent can be an immunosuppressive, or an anti-arthritis agent. The administration of the anti-arthritis agent and the suppressive ODN can be sequential or simultaneous.

In particular examples, the anti-arthritis agent is a biological response modifier, such as Kineret® (anakinra), Enbrel® (etanercept), or Remicade® (infliximab), a disease-modifying antirheumatic drug (DMARD), such as Arava® (leflunomide), a steroid, such as prednisone or cortisone, a nonsteroidal anti-inflammatory drug (NSAID), such as celecoxib, choline magnesium trisalicylate, diclofenac, diclofenac potassium, diclofenac XR, diflunisal, etodolac, etodolac ER, fenoprofen, flurbiprofen oral, ibuprofen, indomethacin, indomethacin SR, indomethacin suppositories, ketoprofen, ketoprofen ER, meclofenamate, meloxicam, nabumetone, naproxen, naproxen CR, naproxen ER, oxaprozin, piroxicam,

rofecoxib, salsalate, sulindac, or tolmetin sodium, or another product, such as Hyalgan® (hyaluronan) or Synvisc® (hylan G-F20).

Thus, the suppressive ODNs disclosed herein may be administered to a subject for the treatment of inflammatory arthropathies in that individual. ODN administration can be systemic or local. Local administration of the ODN is performed by methods well known to those skilled in the art. By way of example, one method of administration to the knee, hip and/or shoulder of an individual is by intra-articular injection. For administration to the knee, for example, the joint to be injected is washed with a betadine solution or other antiseptic. A solution of an anesthetic, such as about one percent lidocaine hydrochloride is injected into the skin and subcutaneous tissue. A 3-way stopcock/needle assembly is utilized to administer the compound via an 18-30 gauge needle. The ODN is injected into the joint space using a standard lateral approach well known to those skilled in the art. The needle and needle tract are cleansed by flushing with 1% lidocaine hydrochloride through the 3-way stopcock assembly as the needle is withdrawn. The knee is then moved through a flexion-extension arc and then immobilized in full extension. The patient is then confined to bed for approximately 24 hours to minimize movement and minimize leakage of ODN from the joint.

In other embodiment, the administration of the suppressive ODN is systemic. Oral, intravenous, intra-arterial, subcutaneous, intra-peritoneal, intra-muscular, and even rectal administration is contemplated.

Other embodiments are methods of treating or preventing inflammatory arthropathies in a subject that involves contacting immune cells with a suppressive ODN, and transferring the immune cells to a subject having or at risk of developing inflammatory arthropathies, thereby treating or preventing the inflammatory arthropathies. Without being bound by theory, these immune cells act to suppress immune activation in a subject. One specific, non-limiting example is dendritic cells. Thus, in certain examples, the immune cells, such as dendritic cells, are contacted with a suppressive ODN, and subsequently administered to a subject. The immune cells can be delivered alone, in conjunction with a suppressive ODN, and/or in conjunction with an additional immunosuppressive agent. The immune cells can be delivered either systemically or locally. In several specific, non-limiting

examples, the cells are delivered parenterally, intravenously, intra-muscularly, subcutaneously, or intra-articularly.

Precise, effective quantities of cells can be readily determined by those who are skilled in the art and will depend, of course, upon the exact condition being treated by the particular therapy being employed. The cells can be transplanted to a desired location, or can be administered intravenously. Other agents, such as growth factors or immunosuppressive agents, can be administered in conjunction with the immune cells.

10 D. Kits

Further embodiments of the disclosure include kits useful for administering the suppressive ODN described herein *in vivo* or *in vitro*. For example, a kit useful for treating a subject with inflammatory arthropathies would comprise an appropriate dosage of suppressive ODN, as well as, optionally, any agents useful for enhancing the inhibitory effect of suppressive ODN. Other embodiments further include instructions for using the kit, and/or pre-filled syringes for administering the ODN to a subject.

Thus, in one embodiment, a kit is provided including a container of suppressive ODN (a sufficient amount for either a single use or multiple uses), and instructions the suppressive ODN. The instructions can be in written form, or can be provided in an electronic format, such as on a diskette or a CD-ROM. Instructions can also be provided in the form of a video cassette.

The subject matter of the present disclosure is further illustrated by the following non-limiting Examples.

25

EXAMPLES

Example 1

Reduction of CpG-Induced Arthritis by Suppressive Oligodeoxynucleotides

This example demonstrates the influence of CpG DNA and suppressive ODNs on the propensity of the host to develop arthritis, and indicates that the

30

mechanism of suppressive ODN action is mediated by Cd11c positive cells.

A. General methods

Animals:

- 5 Female BALB/c mice were obtained from the Jackson Laboratories (Bar Harbor, Maine). The studies were conducted using 8-20 week old mice.

Oligodeoxynucleotides:

- ODNs were synthetically produced. Sequences of the phosphorothioate
10 ODN used were:

CpG: GCTAGACGTTAGCGT (SEQ ID NO: 30)
suppressive: CCTCAAGCTTGAGGGG (SEQ ID NO: 1)
control: GCTAGATGTTAGCGT. (SEQ ID NO: 31)

All ODN were free of detectable protein or endotoxin contamination.

15

Experimental protocol:

- 25 $25 \mu\text{g}$ of ODN in $6 \mu\text{l}$ of PBS was injected into the knee joint using a 30 gauge needle. In some studies, knees were re-injected with PBS or $25 \mu\text{g}$ of suppressive ODN 24-48 hours after initial CpG ODN administration. Joint swelling
20 was measured in the coronal plane using a micrometer caliper. Histologic analysis was performed by a blinded investigator on fixed, decalcified and paraffin embedded sections stained with hematoxylin/eosin.

TNF α assays:

- 25 Single spleen cell suspensions were prepared in RPMI-1640 supplemented with 5% heat inactivated fetal calf serum, 1.5 mM L-glutamine and 100 U/ml of penicillin/streptomycin. 5×10^5 cells/well were cultured in flat-bottomed microtiter plates (Costar, Corning, New York) with ODN for 72 hr. TNF α levels in culture supernatants were measured by ELISA. In brief, 96-well Immulon H2B plates were
30 coated with anti-TNF α Ab (Genzyme, Cambridge, Massachusetts). Plates were blocked with PBS - 1% BSA and overlaid with culture supernatants. Bound

cytokine was detected by the addition of biotin labeled anti-TNF α Ab (Genzyme, Cambridge, Massachusetts) followed by phosphatase-conjugate avidin.

RT-PCR:

5 Total RNA was extracted from homogenized knees using TRIzol reagent (GibCO Life Technologies, Gaithersburg, Maryland) as recommended by the manufacturer. 5 μ g of total RNA was reverse transcribed into cDNA, which was assayed for TNF α (sense ATGAGCACAGAAAGCATGATC; SEQ ID NO:32, antisense TACAGGCTTGTCACCTCGAATT; SEQ ID NO:33, 275 bp) and β -actin
10 (sense GACATGGAGGAGTCTGGCACCACA; SEQ ID NO:34, antisense ATCTCCTGCTCGAAGTCTAGAGCAA; SEQ ID NO:35, 440 bp) by PCR as previously described (Takeshita *et al.*, *Neuroreport* (2001) 12:3029-3032). Relative band intensity was determined by ethidium bromide staining of 1% agarose gels using NIH-Image software.

15

Statistical analysis:

Statistically significant differences between two groups were determined using the Wilcoxon Rank Sum Test. When comparing more than two groups, a two-tailed non-parametric ANOVA with Dunn's post-test analysis was used. Differences
20 in joint diameters were analyzed by repeated-measures ANOVA using the Proc Mixed procedure from the Statistical Analysis System (SAS). A p value of <0.05 was considered significant.

B. Induction of arthritis by CpG ODN

25 Microbial infection of the gastrointestinal (GI) or genitourinary (GU) tracts is associated with the development of reactive arthritis in humans. Evidence indicates that bacterial DNA contributes to this process, since 1) bacterial DNA can be detected in arthritic joints (Braun *et al.*, *J. Rheumatol.* (2000) 27:2185-2192), and 2) bacterial DNA induces joint inflammation when injected into the knees of normal
30 mice (Deng *et al.*, *Nat. Med.* (1999) 5:702-705). Deng *et al.* established that immunostimulatory CpG motifs were the cause of this inflammation by showing that CpG-containing oligodeoxynucleotides (ODN) induced disease in a manner

similar to that induced by purified bacterial DNA (Deng *et al.*, *supra*). This effect is consistent with the proinflammatory properties of CpG ODN, including their ability to stimulate immune cells to proliferate, differentiate, and secrete proinflammatory chemokines and cytokines (Deng *et al.*, *supra*; Klinman *et al.*, *Springer Semin.*

5 *Immunopathol.* (2000) 22:173-83).

Consistent with the findings of Deng *et al.* (Deng *et al.*, *Arthritis Rheum.* (2000) 43:356-364), BALB/c knees injected with CpG ODN developed inflammatory arthritis within 24 hr that peaked after 3-7 days (Fig. 2). CpG-induced arthritis was characterized by swelling (0.14 ± 0.04 millimeters (mm) versus 0.02 ± 0.02 , $p = 0.054$) and histological changes that included perivascular infiltration by mononuclear cells and hyperplasia of the synovial lining (Fig. 2). These inflammatory effects were CpG-specific and localized, since no disease was observed in contra-lateral knees injected with PBS or control ODN. Similar swelling and histologic changes were observed in knees injected with bacterial

10 DNA.

15

C. *Suppressive ODN block the development of CpG-induced arthritis*

To determine whether suppressive ODN prevent CpG mediated inflammatory arthritis, knees were co-injected with 25 μ g of suppressive plus 25 μ g of CpG ODN. The inclusion of suppressive ODN reduced swelling from 0.14 ± 0.04 mm to 0.02 ± 0.02 mm ($p = 0.004$) and the inflammatory score from 1.94 ± 0.32 to 0.67 ± 0.12 ($p = 0.018$, Fig. 2). When joint inflammation was assessed by magnetic resonance imaging, suppressive ODN reduced CpG ODN induced fluid accumulation from 95.4 ± 8.2 MR-signal intensity units to 52.3 ± 6.7 units ($n = 5$, $p < 0.001$). These effects were specific, since co-administering PBS or control ODN had no impact on CpG-induced arthritis (Fig. 2). In parallel studies, suppressive ODN prevented the arthritis induced by bacterial DNA but not lipopolysaccharide (LPS).

20

25

30 D. *Kinetics of the ODN anti-inflammatory effect*

To examine the kinetics of this anti-inflammatory effect, suppressive ODN were administered 0, 24 and 48 hours after CpG ODN injection. To control for the

effect of multiple injections, the contralateral knee was injected with PBS, and the difference in swelling between the two joints evaluated daily. A significant reduction in swelling was observed when joints were treated with suppressive ODN up to two days after CpG administration ($p=0.012$, Fig. 2C). However, maximal control of arthritis required early intervention ($p=0.011$, D0 vs D2).

E. Suppressive ODNs reduce intra-articular TNF production

Previous studies established that the magnitude of CpG-induced arthritis correlated with intra-articular TNF α levels (Deng *et al.*, *Arthritis Res.* (2001) 3:48-53). Consistent with TNF α playing a critical role in the disease process, TNF α knock out mice fail to develop CpG-induced arthritis (Deng *et al.*, *Arthritis Rheum.* (2000) 43:356-364; Ronaghy *et al.*, *J. Immunology* (2002) 168:51-56). To evaluate whether suppressive ODN had an effect on TNF α production, BALB/c spleen cells were stimulated *in vitro* with CpG + suppressive ODN. As seen in Fig. 3, suppressive ODN reduced TNF α production in a dose-dependent manner, whereas control ODN had no effect.

To monitor the *in vivo* effect of suppressive ODN on TNF production, cytokine mRNA levels were measured in the joint. Consistent with earlier reports (Deng *et al.*, *Arthritis Rheum.* (2000) 43:356-364; Ronaghy *et al.*, *J. Immunology* (2002) 168:51-56; Kyburz *et al.*, *Arthritis Rheum.* (2001) 44 (Suppl): S396), CpG ODN up-regulated local TNF mRNA levels (Fig. 3C, D). Co-administering suppressive ODN reduced TNF mRNA by >50% ($p<0.003$, Fig. 3).

Example 2

Systemic Effect of Stimulatory and Suppressive Oligodeoxynucleotides on the Induction of Inflammatory Arthritis

Animals:

Female BALB/c mice were obtained from the Jackson Laboratories (Bar Harbor, Maine). The mice were used at 8-20 weeks of age and were housed under specific pathogen free conditions.

Oligonucleotides:

- ODN used in this study had a phosphorothioate backbone, and were chemically synthesized. They contained <0.1 endotoxin units (EU) of endotoxin per mg of ODN, as assessed by a Limulus ameocyte lysate assay (QCL-1000, BioWhittaker). The sequence of the CpG ODN was GCTAGACGTTAGCGT (SEQ. ID NO: 30), of the suppressive ODN: CCTCAAGCTTGAGGGG (SEQ. ID NO: 1), and of the control ODN: GCTAGATGTTAGCGT (SEQ ID NO: 31).

Experimental protocols:

- Arthritis was induced as previously described in Zeuner *et al.*, *Arthritis Rheum.* (2002). Briefly 1 or 25 µg of ODN in 6 µl of PBS was injected into the knee joint using a 30 gauge needle. Joint swelling was measured in the coronal plane using a micrometer caliper (General Tools Mfg CO, NY, NY). Mice were euthanized on day 4 and the knees fixed, decalcified, sectioned, and stained with hematoxylin/eosin prior to histologic examination. Scoring was performed by a blinded investigator using a scale of 0-4. 0=absence of inflammation, 1=sparse, localized perivascular infiltrate, 2=moderate infiltrate, 3=moderate-dense infiltrate with synovial hyperplasia, 4=dense infiltrate with pronounced synovial hyperplasia.

- In some experiments, donor mice were injected intraperitoneally (i.p.) with 300 µg of ODN in PBS. A single cell suspension prepared from the spleens of these mice was prepared, and 20×10^6 transferred intravenously (IV) to naive littermate recipients. These spleen cells were enriched or depleted of various subpopulations using magnetic bead separation (Vario-Macs System, Miltenyi) as recommended by the manufacturer.

25

Statistical Analysis:

- Differences between two groups determined using the Wilcoxon Rank Sum Test. Differences between multiple groups were evaluated using a two-tailed analysis of variance (ANOVA) on Ranks with Dunn's post test analysis.
- Differences in joint diameters were compared by repeated-measures ANOVA. A p value of <0.05 was considered significant. Data are presented as mean +/- SEM.

B. *Effect of systemic CpG ODN on sensitivity of joints to inflammatory stimuli*

Previous studies established that intra-articular injection of bacterial DNA or CpG ODN induces arthritis in mice, characterized by an inflammatory cell infiltrate, perivascular accumulation of mononuclear cells, and hyperplasia of the synovial lining (Deng and Tarkowski, *Arthritis Rheum.* (2000) 43:356-364). Since reactive
5 arthritis in humans is associated with infection of the gastrointestinal (GI) or genitourinary (GU) tract rather than the joint, we explored whether CpG DNA in the systemic circulation might alter the sensitivity of joints to inflammatory stimuli.

To examine this possibility, normal BALB/c mice were injected IP with 300
10 μ g of CpG DNA, and then challenged with a sub-arthritis dose of local CpG ODN. As seen in Fig. 5, normal mice and mice treated with PBS or control ODN did not develop arthritis (no inflammation, no swelling) when injected with 1 μ g of CpG. In contrast, animals pre-treated with systemic CpG DNA developed
15 significant joint swelling, a mononuclear cell infiltrate, and synovial hyperplasia when challenged with the same dose of CpG ODN. These changes were triggered by exposure to local CpG DNA, as no inflammation developed when the joints of systemically treated animals were injected with PBS.

These findings indicate that CpG DNA in the systemic circulation (perhaps released by dying bacteria in the GI or GU tract) can increase the host's
20 susceptibility to the development local arthritis.

C. *Systemic administration of suppressive ODN reduces susceptibility to arthritis*

It has been demonstrated that suppressive ODN (containing motifs that
25 selectively inhibit the immunostimulatory activity of CpG ODN) significantly reduce the swelling, synovial hyperplasia and leukocyte infiltration induced by CpG DNA. These effects were observed when suppressive ODN were injected directly into arthritic joints. Because systemic CpG DNA can increase the host's susceptibility to arthritis, suppressive ODN in the systemic circulation might lower
30 this susceptibility.

To test this hypothesis, BALB/c mice were treated intraperitoneally with 300 μ g of suppressive ODN 0-3 days prior to the intra-articular injection of 25 μ g CpG

DNA. Consistent with previous studies, naive mice (and mice pre-treated with control ODN or PBS) developed severe arthritis following local CpG ODN challenge (Fig. 6). In contrast, systemic administration of suppressive ODN three days prior to local CpG DNA challenge reduced joint swelling and inflammation by 80 - 85% (Fig. 7; $p < 0.029$). Unlike the situation with locally administered suppressive ODN, which reduced inflammation when administered up to two days after the induction of arthritis, suppressive ODN were effective systemically only if delivered several days prior to the induction of arthritis. These findings demonstrate that instead of blocking CpG induced arthritis locally, suppressive ODN in the systemic circulation activate a regulatory cascade that requires several days to mature.

D. Spleen cells from suppressive ODN treated mice prevent CpG-induced arthritis

Spleen cells from mice treated systemically with suppressive ODN were transferred to naive controls, which were then injected with 25 μ g of CpG DNA intra-articularly. As expected, spleen cells from untreated donors had no effect on the development of CpG-induced arthritis (Fig. 8). By comparison, the transfer of 20×10^6 spleen cells from suppressive ODN treated donors significantly reduced joint swelling and inflammation in the recipients. These findings indicate that systemically administered suppressive ODN elicit a population of regulatory cells that inhibit CpG-induced arthritis.

To define the time course over which these regulatory cells are generated, splenocytes were isolated from one to three days after treatment with suppressive ODN. Cells from animals treated with suppressive ODN for three days significantly inhibited CpG-induced arthritis, whereas splenocytes from animals exposed to suppressive ODN for shorter periods were progressively less effective.

To characterize the cell type responsible for this resistance to CpG-induced arthritis, magnetic beads were used to deplete or enrich specific cell subpopulations from donor spleens. Depletion of CD19⁺ B cells, T cells, or NK cells had no effect on CpG-induced arthritis (Fig. 9). However, removal of CD11c⁺ dendritic cells resulted in a complete abrogation of the suppressive activity of the transferred spleen

cell population. Similarly, the transfer of only 5×10^5 CD11c⁺ enriched cells from suppressive ODN treated mice to normal recipients conferred resistance to CpG-induced arthritis.

Example 3

Repetitive Elements Present in Mammalian Telomeres Suppress Bacterial DNA-Induced Immune Activation

This example demonstrates the ability of TTAGGG multimers to inhibit CpG-induced immune activation.

A. General Methods

Reagents

Endotoxin-free phosphorothioate or phosphodiester ODNs were chemically synthesized. 7-DG modified ODNs were synthesized using the 10-campthorsulphonyl-oxaziridine oxidization protocol recommended by the manufacturer (Glen Research, Sterling, VA). Mammalian DNA was isolated from calf thymus and murine spleen (Wizard Genomic DNA purification kit, Promega, Madison, WI). E. coli was obtained from Sigma (St. Louis, MO). Telomerase knockout mice were obtained from Johns Hopkins Univ., Baltimore, MD. All DNA obtained from commercial providers was re-purified to eliminate endotoxin (<0.1 U/mg). Double stranded DNA was converted to single stranded DNA by heat denaturing at 95°C for five minutes followed by cooling on ice. BAL-31 (New England Biolabs, Beverly, MA) digestion of CT DNA was continued for 2 hours at 30°C according to manufacturer's recommendations. At the end of the incubation, the enzyme was inactivated at 65°C for 10 minutes. Plasmid encoding for 1.6 kb long TTAGGG repeat was obtained from University of Texas Southwestern Medical Center, Dallas, TX. Non-telomere coding plasmid was from Vical (San Diego, CA.).

Mice

Specific pathogen-free male BALB/c mice (Jackson Laboratories, Bar Harbor, ME) were housed in sterile micro-isolator cages in a barrier environment

and injected intraperitoneally with 400 µg of CpG ODN plus 200 µg of suppressive or control ODN. Spleen cells were harvested 6 hours later and monitored for cytokine production after 36 hours. In order to measure the pEPO transgene expression levels, female Balb/c mice (4-6 weeks old) were injected with 30 µg of pVRmEPO (Vical, San Diego, CA) plasmid in sterile saline into the anterior tibialis muscle alone or in combination with 50 µg of control or suppressive ODN. Hematocrits were measured as described (Tripathy *et al.*, *Proc Natl Acad Sci U S A.* 93:10876-80, 1996) on blood collected by tail vein puncture.

10 *Cytokine and IgM ELISA assays*

Immulon 2 microtiter plates (Dynex Technologies Inc., Chantilly VA) were coated with anti-cytokine or anti-IgM antibodies (Pharmingen, San Diego CA) and then blocked with PBS - 1% bovine serum albumin (BSA). Serially diluted culture supernatant or serum was added for two hours. Cytokine was detected using biotinylated anti-cytokine antibody followed by phosphatase-streptavidin (Pharmingen) whereas bound IgM was detected using phosphatase-conjugated anti-IgM antibodies (Southern Biotechnology Associates, Birmingham, AL) as described.

20 *Detection of co-stimulatory molecule expression by FACS*

2 x 10⁶ spleen cells/ml were incubated with ODN for 24 hours. Cells were washed, fixed with 5% paraformaldehyde for 15 minutes, and stained with PE-labeled anti CD-40, anti CD-86, and anti ICAM-1 (Pharmingen, San Diego, CA.) for 30 minutes at room temperature. Cells were washed, re-suspended in PBS/BSA (supplemented with Azide), and analyzed by fluorescence activated cell sorting (FACSort, Becton Dickinson, San Jose, CA).

Cytokine RT-PCR

Spleen cells were isolated 6 hours after CpG ODN injection. Total RNA was extracted, reverse-transcribed, and amplified in a standard PCR reaction for 24 cycles using primers specific for murine interleukin-6 (IL-6), interleukin-12 (IL-12), and interferon (IFN) as previously described. PCR amplified material was separated

on 1.5% agarose gels and visualized under ultraviolet (UV) light after ethidium bromide staining.

In vitro DNA-PK assay

5 DNA-dependent protein kinase activity was measured as recommended by the manufacturer (Promega, Madison, WI). Briefly, 20 units of affinity-purified human DNA- PKcs and 10 nM of ODN were incubated with 0.4 mM biotinylated peptide substrate and P₃₂-ATP for 5 minutes at 30°C in reaction buffer. Phosphorylated substrate was captured on streptavidin coated SAM membranes
10 (Promega), and measured in a scintillation counter.

Cell transfection and luciferase assay

HEK 293 (5x10⁴) cells (ATCC, Manassas, VA) were transfected with 0.8 µg of vector plasmid (pCIneo, Promega, Madison, WI), pCIneo-mTLR9, plus 0.1 µg of
15 p5xNF- κB-luc (Stratagene, Lajolla, CA.) and 0.1 µg of pSV-beta-galactosidase (Promega) and incubated overnight at 37°C. The cells were then stimulated with indicated ODN for 24 h. Cells were then harvested and luciferase assay was performed as recommended by the manufacturer (Promega). Beta-galactosidase activity was used to normalize the data.

20

Measurement of circular dichroism

A Jasco J-720A spectropolarimeter was used to measure the circular dichroism of ODN (50 g/ml in 0.1X PBS). Data is expressed as the mean peak ellipticity (mdeg/abs) of 5-10 readings/sample in the 260-270 nm range.

25

Statistical analysis

In vitro assays were performed in triplicate on at least three different spleen cell preparations. All *in vivo* experiments were performed on a minimum of five to ten mice/group. Statistical significance was evaluated using Student's t test.

30 Correlation analysis is computed by linear correlation analysis between CD data vs % suppression.

B. TTAGGG multimers inhibit CpG-induced immune activation

The ability of TTAGGG multimers to inhibit CpG-induced immune activation was tested. Initial experiments showed that ODNs containing suppressive motifs inhibit CpG-induced immune activation in a dose-dependent fashion (Fig.

5 10A).

ODNs containing the largest number of TTAGGG repeats (n=4) were the most suppressive ($p < 0.001$; Fig. 10B). Single TTAGGG hexamers were suppressive only when incorporated into larger ODNs (≥ 10 bases in length), and were somewhat less active than TTAGGG multimers. TTAGGG motifs were suppressive both in *cis* 10 and in *trans*; they inhibited immune activation when present on the same or on a different strand of DNA than that expressing the stimulatory CpG sequence (Fig. 10C and D). This inhibitory activity was exquisitely specific: even high concentrations of suppressive ODNs had no effect on mitogen-induced immune responses (Fig. 10D), indicating that suppressive ODN were neither toxic nor non- 15 specifically immunosuppressive.

C. Suppression is mediated by poly-G sequences

The bases contributing to this suppressive activity were identified by systematically modifying ODNs containing single TTAGGG motifs. Substitutions 20 outside the telomere-derived sequence did not significantly affect suppression. Replacing multiple bases in the TTA region of the TTAGGG motif also had little effect on the suppressive activity (Fig. 10E). In contrast, replacing two or more of the Gs in this motif substantially reduced the ODN's ability to block CpG-induced immune activation (Fig. 10E). These results indicate that suppression is mediated 25 by the poly-G sequence itself, or the two-dimensional structure imposed by that sequence.

D. Suppression is mediated by the two-dimensional structure of the motifs

To differentiate between these alternatives, individual Gs were replaced by 30 7-deaza guanosine (7-DG) analogues. These 7-DG substitutions did not alter the base sequence of the ODN but did prevent Hoogsteen hydrogen bonding between guanosines, thereby reducing G tetrad formation (Hurley *et al.*, *Trends Pharmacol.*

5 *Sci.* 21:136-142, 2000; Lilley *et al.*, *EMBO J.* 13:993-1001, 1994). The resultant loss in secondary structure is reflected by a loss in circular dichroism (Lilley *et al.*, *EMBO J.* 13:993-1001, 1994). ODNs capable of forming G tetrads typically have peak CD values >2, while those without such secondary structure have circular dichroism values <1.4 (Fig. 10).

Introducing a 7-DG substitution significantly reduced an ODN's ability to form a G-tetrad and to mediate suppression ($p < 0.001$, Fig. 11). To confirm that G-tetrad formation was critical to suppression, ODNs were synthesized that lacked the TTAGGG motif but still formed G-tetrads. These novel ODNs suppressed CpG
10 ODN and bacterial DNA induced immune stimulation by >90% ($p < 0.001$; Fig. 10F). Indeed, there was a consistent correlation between G-tetrad forming ability and suppressive activity ($R = 0.832$, Fig. 11B).

15 *E. Mechanism of suppressive ODN activity*

The mechanism by which suppressive ODNs inhibit immune activation was explored. Both bacterial DNA and CpG ODN stimulated DNA- dependent protein kinase activity *in vitro*. Of particular interest, this activity was specifically blocked by TTAGGG multimers and other G tetrad forming ODN, but not their 7-DG modified analogues. These findings indicate that suppressive motifs inhibit CpG-
20 dependent DNA-PK_{cs} activation of immune cells. In contrast, suppressive ODNs did not block the binding or internalization of CpG ODNs mediated by Toll-like receptor 9.

Example 4

25 **Effect of Suppressive ODNs on CpG-induced Immune Action**

This example demonstrates the kinetics, magnitude, and nature of the immune inhibition elicited by suppressive motifs. Previous studies established that the immunostimulatory activity of CpG DNA can be reversed several hours later either by removing the stimulatory DNA or adding suppressive DNA. The same
30 cells that interact with stimulatory motifs also recognize suppressive motifs. When both sequence types are present on the same strand of DNA, recognition proceeds in

5' → 3' direction. Suppression is generally dominant over stimulation, although a motif in the 5' position can interfere with recognition of a motif immediately downstream. Understanding the rules governing cellular responses to stimulatory and suppressive motifs facilitates the design of ODN for therapeutic uses.

5

A. General Methods

Animals:

Female Balb/c mice were obtained from the Jackson Laboratories (Bar Harbor, Maine). The mice were housed under specific pathogen free conditions, and used at 8-20 weeks of age. All studies involved protocols approved by the CBER Animal Care and Use Committee.

Oligodeoxynucleotides:

Studies utilized phosphorothioate modified ODNs that were synthesized at the CBER core facility Verthelyi, D., *et al.*, *J Immunol* (2001) 166:2372. The following ODNs were used: immunostimulatory ODN1466 (TCAACGTTGA; SEQ. ID NO: 26) and ODN1555 (GCTAGACGTTAGCGT; SEQ. ID NO: 27), control ODN1471 (TCAAGCTTGA; SEQ. ID NO: 28) and ODN1612 (GCTAGAGCTTAGGCT; SEQ. ID NO: 29), suppressive ODN1502 (GAGCAAGCTGGACCTTCCAT; SEQ. ID NO: 20) and ODNH154 (CCTCAAGCTTGAGGGG; SEQ. ID NO: 1). Underlined bases represent the 10-mer sequences that were incorporated into complex multi-determinant ODN used in some experiments. There was no detectable protein or endotoxin contamination of these ODN.

Mammalian DNA was purified from BALB/c spleens (Wizard Genomic DNA purification kit, Promega, Madison, WI). *E. coli* DNA was obtained from Gibco BRL (Rockville, MD, USA). Endotoxin contamination in these preparations was <0.1 U/ml after purification Klinman, D. M., *et al.*, *J. Immunol.* (1997) 158:3635. Double stranded DNA (dsDNA) was converted to single stranded DNA (ssDNA) by heat denaturing at 95°C for 5' followed by immediate cooling on ice.

Cytokine ELISA assays:

Single spleen cell suspensions were washed three times and re-suspended in RPMI- 1640 supplemented with 5% heat inactivated fetal calf serum (FCS), 1.5 mM L- glutamine and 100 U/ml of penicillin/streptomycin. 5×10^5 cells/well were
5 cultured in flat-bottomed microtiter plates (Costar, Corning, New York) with 1 μ M ODN for 18 - 24 h. Culture supernatants were collected, and cytokine levels measured by ELISA. In brief, 96 well Immulon H2B plates were coated with cytokine-specific antibodies and blocked with PBS 1% BSA as previously described in Klinman and Nutman, *Current Protocols in Immunology* (1994), Coligan,
10 Kruisbeek, Margulies, Shevach, and Strober, eds., Greene Publishing Associates, Brooklyn, NY. Culture supernatants were added, and bound cytokine detected by the addition of biotin labeled secondary antibodies followed by phosphatase-conjugated avidin and a phosphatase-specific colorimetric substrate (PNPP, Pierce, Rockford, Illinois). Standard curves were generated using recombinant cytokines.
15 The detection limit for these assays was: 0.8 U/ml for IFN γ , 0.1 ng/ml for IL-6 and 0.1 ng/ml for IL-12. All assays were performed in triplicate.

Cytokine-specific ELISpot assays:

A single spleen cell suspension prepared in RPMI 1640 plus 5% FCS was
20 serially diluted onto plates pre-coated with anti-cytokine antibodies. (see Klinman and Nutman, *Current Protocols in Immunology* (1994), Coligan, Kruisbeek, Margulies, Shevach, and Strober, eds., Greene Publishing Associates, Brooklyn, NY). Cells were incubated with 1 μ M ODN at 37°C for 8-12 hours, and their secretion of cytokine detected colorimetrically as previously described (Klinman and
25 Nutman, *Current Protocols in Immunology* (1994), Coligan, Kruisbeek, Margulies, Shevach, and Strober, eds., Greene Publishing Associates, Brooklyn, NY).

Cell-surface binding and internalization of ODN:

Spleen cells (2×10^6 /ml) were incubated with 1 μ M of unlabeled and/or
30 fluorescent- labeled ODN for 10 minutes at 4°C (binding experiments) or at 37°C for 1 hour (uptake experiments Gursel *et al.*, *J.Leuko.Biol.* (2001). Cells were washed, fixed, and analyzed by FACScan (Becton Dickinson, San Jose, CA).

Statistical analysis:

Statistically significant differences between two groups were determined using the Wilcoxon Rank Sum Test. When comparing more than two groups, differences were determined using a 2-tailed non-parametric ANOVA with Dunn's post-test analysis. A p value of <0.05 was considered significant.

B. Mammalian DNA suppresses CpG DNA-induced immune activation

Single stranded bacterial DNA and synthetic ODN containing unmethylated CpG motifs stimulate immune cells to mature, proliferate and produce cytokines, chemokines, and immunoglobulins. (Klinman *et al.*, *Proc. Natl. Acad. Sci. USA* (1996) 93:2879; Roman *et al.*, *Nature Medicine* (1997) 3:849; Roman *et al.*, (1997) *Nature Medicine* 3:849; Yamamoto *et al.*, (1992) *J. Immunol.* 148:4072; Krieg *et al.*, (1995) *Nature* 374:546). These effects can be blocked by "poly-G" and/or "GC" rich DNA motifs (Krieg *et al.*, (1998) *Proc. Natl. Acad. Sci.* 95:12631; Pisetsky *et al.*, (1995) *NY Acad. Sci.* 772:152). Scores of ODNs were synthesized and tested, and eventually several were identified that selectively inhibited CpG-induced immune responses. The two most active of these suppressive ODN (ODN1502 and ODNH154) were selected for detailed study. As seen in Fig. 12, suppressive ODN blocked a majority of the IFN γ production induced by bacterial DNA or CpG ODN ($p < .01$). Suppressive ODN were neither toxic nor broadly immunosuppressive, as they did not interfere with the mitogenic activity of LPS or Concavalin A (Con A; Fig. 12).

The activity of suppressive ODNs was concentration dependent, with 50% suppression being achieved at a suppressive to CpG ODN ratio of approximately 1:3 (Fig. 13). To examine the kinetics of this inhibition, suppressive ODN were added to BALB/c spleen cells at various times after CpG-induced stimulation. Maximal inhibition was observed when suppressive ODN were co-administered with CpG ODN, although statistically significant inhibition persisted when suppressive ODN were added up to 3 hours later (Fig. 14). These findings indicate that CpG induced immune activation is an ongoing process, and can be inhibited after the stimulatory signal is delivered.

To test this conclusion, spleen cells were incubated with CpG ODN for various periods and cytokine production analyzed after 24 hours. Cells stimulated with CpG DNA for 8 hours produced 90% as much cytokine as cells stimulated continuously for 24 hours (Fig. 15). Cells treated with CpG ODN for only 4 hours produced half as much cytokine, while cells treated with CpG DNA for < 2 hours showed only minimal activation (Fig. 15). These findings support the conclusion that CpG-induced cellular activation is reversible for several hours.

C. *Suppressive ODNs do not block CpG ODN uptake or induce the production of inhibitory factors*

The results described above indicate that CpG-induced immune activation can be reversed either by adding suppressive ODNs or by removing stimulatory ODNs. This indicates that suppressive ODNs block the ongoing uptake of CpG DNA. Yet FACS analysis demonstrated that neither cell surface binding nor internalization of fluorescein isothiocyanate (FITC)-labeled CpG ODN was significantly reduced by suppressive ODN at concentrations that blocked cytokine production by approximately 75% (Fig. 16).

The possibility that suppressive motifs might induce the production of a factor that blocks CpG-dependent immune activation was then investigated. Initial studies established that BALB/c spleen cells pre-incubated with suppressive ODN remained unresponsive to CpG-induced stimulation for several hours (Table I, line 3). If this non-responsive state was mediated by a soluble factor (or inhibitory cell-cell interactions) then cells pre-treated with suppressive ODN should block CpG-induced stimulation of naive spleen. As seen in Table I, cells treated with suppressive ODN had no significant effect on CpG dependent cytokine production by fresh splenocytes.

Table I
Effect of mixing cells treated with suppressive versus stimulatory ODN

Cells pre-treated with suppressive ODN	Fresh cells	ODN added during culture	% maximal cytokine production	
			IL-6	IL-12
-	+	CpG	100 ± 13	100 ± 6
-	+	Control	3 ± 2	7 ± 2
+	-	CpG	9 ± 6	6 ± 2
+	-	Control	0 ± 0	0 ± 0
+	+	CpG	86 ± 16	105 ± 12
+	+	Control	0 ± 0	0 ± 0

5 BALB/c spleen cells were treated with 1 μ M suppressive ODN₁₅₀₂ for 2 hours and then washed (first column). These cells were added to naive splenocytes (second column) plus 1 μ M of control ODN₁₄₇₁ or CpG ODN₁₅₅₅. IL-6 and IL-12 levels in culture supernatants were measured by ELISA after 18 hours. Results represent the average \pm SD of triplicate assays, each standardized to the response induced by bacterial DNA (62 pg/ml IL-6; 134 pg/ml IL-12).

D. Cellular recognition of suppressive versus stimulatory motifs

The above studies establish that suppressive motifs on one strand of DNA block the immune activation induced by stimulatory motifs on a different strand (trans suppression). To better understand the interaction between suppressive and stimulatory motifs, ODNs containing both were synthesized. In the simplest case, a 20-mer was constructed in which a CpG motif was placed immediately 5' to a suppressive motif (referred to as [CpG - Sup] ODN).

Experiments showed that this ODN was stimulatory, triggering murine spleen cells to produce IL-6, IL-12 and IFN γ to the same extent as an ODN of the same length in which the suppressive motif was replaced by a 'control' sequence (one that was neither stimulatory nor suppressive, Table II). [CpG - Sup] ODNs also failed to block the immune activation induced by an independent CpG ODN (Table II). These results indicate that a suppressive motif is inactive when located immediately 3' to a CpG motif on the same strand of DNA. Similar results were obtained in studies of additional [CpG - Sup] ODNs that utilized different stimulatory and suppressive motifs.

Table II
Effect of motif position on immunostimulatory activity

Location of motifs (5' → 3')	# of cytokine secreting cells		
	IL-6	IL-12	IFN γ
CpG ODN *	79 \pm 13	1980 \pm 230	260 \pm 40
[CpG - Sup] ODN*	72 \pm 14	2080 \pm 480	230 \pm 60
[Sup-CpG] ODN	0 \pm 0	140 \pm 30	0 \pm 0
[CpG-Cont] ODN*	64 \pm 12	2210 \pm 130	284 \pm 34
[Cont-CpG] ODN*	80 \pm 11	1942 \pm 88	238 \pm 28
[Cont-Sup] ODN	8 \pm 2	184 \pm 34	36 \pm 8
[CpG-Sup] ODN+ Sup	4 \pm 2	226 \pm 38	28 \pm 6
ODN			
[Sup-CpG] ODN + CpG	7 \pm 3	250 \pm 32	34 \pm 9
ODN*			

5

10⁶ BALB/c spleen cells were co-incubated with 1 μ M of each ODN. Complex ODN (20 bp in length) were constructed from 10-mers containing suppressive (Sup), stimulatory (CpG) or control (Cont) motifs. The number of cytokine secreting cells/10⁶ was determined by ELISpot after 24 hours of stimulation. Equivalent results were derived using combinations of motifs derived from two different stimulatory (ODN₁₅₅₅ and ODN₁₄₆₆), control (ODN₁₄₇₁ and ODN₁₆₁₂) and suppressive (ODN₁₅₀₂ and ODN_{H154}) ODN. Results represent the average \pm SD of triplicate assays involving at least two ODN of each type.

* Stimulatory ODN, p < 0.05.

15 To better understand this phenomenon, longer ODNs were synthesized in which the CpG and suppressive motifs were separated by progressively longer CT spacers. Adding a 5 base spacer generated an ODN that was still stimulatory (Table III). However, separating the motifs by >10 bases yielded ODNs that were suppressive, since they blocked the stimulatory activity of co-administered CpG

20 ODNs (Table III).

Table III

Effect of distance between motifs on ODN activity

Cytokine producing cells (% maximum)

ODN	IL-6	IL-12	IFN γ
CpG ODN *	100 \pm 11	100 \pm 7	100 \pm 10
CpG ODN * + Cont ODN	97 \pm 14	98 \pm 9	100 \pm 17
CpG ODN * + Sup ODN	16 \pm 6	21 \pm 6	18 \pm 5
[CpG - Sup] ODN *	87 \pm 12	>100 \pm 14	92 \pm 14
[CpG - 5 bases - Sup] ODN *	>100 \pm 4	>100 \pm 21	>100 \pm 22
[CpG - 10 bases - Sup] ODN	38 \pm 6	64 \pm 15	42 \pm 7
[CpG - 20 bases - Sup] ODN	7 \pm 4	48 \pm 13	24 \pm 8
[CpG - 20 bases - Cont] ODN *	94 \pm 7	>100 \pm 14	99 \pm 11
[Sup - CpG] ODN	0 \pm 0	0 \pm 0	0 \pm 0
[Sup - 20 bases - CpG] ODN	8 \pm 5	9 \pm 3	2 \pm 1
[CpG - Sup] ODN * + CpG ODN *	>100 \pm 16	>100 \pm 15	98 \pm 13
[CpG - 5 bases - Sup] ODN * + CpG ODN *	>100 \pm 18	>100 \pm 11	98 \pm 20
CpG ODN *			
[CpG - 10 bases - Sup] ODN + CpG ODN *	58 \pm 7	75 \pm 9	66 \pm 9
[CpG - 20 bases - Sup] ODN + CpG ODN *	27 \pm 5	26 \pm 10	30 \pm 8
[Sup - CpG] ODN + CpG ODN *	9 \pm 4	11 \pm 4	8 \pm 5
[Sup - 20 CT - CpG] ODN + CpG ODN *	5 \pm 1	9 \pm 3	13 \pm 2

5

BALB/c spleen cells were stimulated *in vitro* with 1 μ M of each ODN, and the number of cells activated to secrete cytokine determined 8 hours later by ELISpot. The percent of cells activated to secrete cytokine was calculated by the formula:

(# of cells activated by test ODN) - (background)/

(# of cells activated by CpG ODN) - (background) X 100%.

Two different control (ODN₁₄₇₁ and ODN₁₆₁₂), CpG (ODN₁₄₆₆ and ODN₁₅₅₃) and suppressive (ODN₁₅₀₂ and ODN₁₅₁₄) ODN gave similar results in these experiments.

Results represent the average of 2-4 assays/data point. Table II shows typical numbers of cytokine secreting cells/10⁶.

* Stimulatory ODN, p < .05.

The trivial possibility that the CT spacer somehow reduced CpG activity was eliminated by substituting a "control" motif for the 3' suppressive motif. The resulting ODNs were fully stimulatory (Table III).

The impact of placing a suppressive motif 5' to a CpG motif was then examined. ODNs with a suppressive motif in the 5' position induced little or no immune activation, even when the CpG motif was shifted up to 20 bp downstream from the suppressive motif (Tables II and III). This lack of activity could not be

attributed to the 3' location of the CpG motif, since CpG ODNs with a 'control' sequence at the 5' end were immunostimulatory. All ODNs containing a suppressive motif in the 5' position also inhibited co-administered CpG ODN (Tables II and III). These findings indicate that the relative position of stimulatory and suppressive motifs determines the immunomodulatory properties of DNA.

Example 5

Suppressive ODNs Block the Development of Collagen-Induced Arthritis

This example demonstrates the ability of suppressive ODNs to block the development of collagen-induced arthritis (an animal model of rheumatoid arthritis).

DBA/1 LacJ mice provide a murine model of human inflammation. Ten to twenty DBA/1 LacJ mice per group were injected with type II collagen in complete Freund's adjuvant (CII/CFA) on day 0, and with type II collagen in incomplete Freund's adjuvant (CII/IFA) on day 21 to induce arthritis (see Figure 17). The study groups included animals treated with 200 µg of suppressive ODN A151, control ODN 1612 or PBS on days -3, 0, 3, 7, 10, 14, 18 and 21. The incidence of arthritis and clinical score were monitored twice weekly. Antigen-specific humoral and cellular immune responses, and local expression of pro-inflammatory cytokines, were also investigated. Table IV shows the incidence of arthritis and clinical score on day 56 of treatment. Treatment with ODN A151 significantly reduced both the percentage of mice that developed arthritis (Figure 18A), and the arthritis clinical score (Figure 18B).

Table IV

Incidence of arthritis and clinical score. Data represent results from day 56.

	Incidence (%)	Clinical Score
PBS-control	95 (19/20)	7.2 +/- 0.7
ODN 1612- treated	90 (9/10)	5.9 +/- 1.1
A151-treated	50 (10/20)	1.7 +/- .04*

*.p < 0.05, as compared with PBS-control or ODN 1612-treated mice.

In addition, production of anti-CII antibody was suppressed by A151 treatment. In Figure 19, sera were collected on day 35 and assayed for IFN γ by ELISA assay, as described above. Standard curves were constructed by serial dilutions of a mixture of sera from arthritic mice. In Figure 20, spleen cells from
5 naive, PBS or A151-treated mice were isolated on day 22 (Figure 20A) or 35 (Figure 20B). Cells were stimulated *in vitro* with 50 μ g/ml of CII for 72 hours and culture supernatants were assayed for IFN-gamma detection.

In vivo (local) expression of proinflammatory cytokine was also suppressed by treatment with ODN A151 (Figure 21). The hind paws of treated animals were
10 removed on day 35. Total RNA was extracted from tissue homogenates, and mRNA of the pro-inflammatory cytokine IL-1 β was monitored by RT-PCR.

While this disclosure has been described with an emphasis upon preferred
embodiments, it will be obvious to those of ordinary skill in the art that variations of
15 the preferred embodiments may be used and it is intended that the disclosure may be practiced otherwise than as specifically described herein. Accordingly, this disclosure includes all modifications encompassed within the spirit and scope of the disclosure as defined by the following claims: